7 PHYSICAL HABITAT

The Maryland Biological Stream Survey (MBSS or the Survey) collects a variety of data to characterize physical habitat and to assess relationships between physical habitat and biota. Observations and measurements include a semi-quantitative assessment of several key habitat parameters, presence/absence of habitat features, measures of stream size and channel geometry, presence and type of riparian vegetation, and assessments of bank stability. With these data, a multimetric index of physical habitat integrity was recently developed for the Survey (Hall et al. 1999b). This chapter synthesizes the results of physical habitat characterization, using both individual measures and the Physical Habitat Index, and explores associations between physical habitat parameters and biological communities.

7.1 BACKGROUND

Stream health, as determined by the condition of biological communities, has been shown to be directly correlated to physical habitat quality (Rankin 1995, Richards et al. 1993, Roth et al. 1996). Previous MBSS reports have described geographic patterns in the physical habitat of Maryland streams and have correlated physical habitat quality with biological resources (Roth et al. 1997, 1998). In this report, we expand on earlier analyses and examine the relationships between physical habitat and stream biota statewide.

Although programs to improve the quality of streams and rivers tend to focus on water chemistry-based definitions of stream quality, physical habitat degradation can have an equal or greater effect on stream ecosystems and their biological communities. Habitat loss and degradation has been identified as one of six critical factors affecting biological diversity in streams worldwide; habitat alteration is cited as a leading cause of fish species extinctions, contributing to 73% of extinctions in North America during this century (Allan and Flecker 1993, Miller et al. 1989). Habitat degradation can result from a variety of human impacts occurring within the stream itself and in the surrounding watershed. Typical instream impacts include sedimentation, impoundment, and stream channelization. Urban development, timber harvesting, agriculture, livestock grazing, and the draining or filling of wetlands are well-known examples of human activities affecting streams at a broader scale.

Alone or in combination, these human activities may cause changes in vegetative cover, sediment loads, hydrology, and other factors influencing stream habitat quality. The amount of vegetative cover in a watershed regulates the flow of water, nutrients, and sediments to adjacent streams. In watersheds impacted by anthropogenic stress, riparian (streamside) forests can ameliorate inputs of nutrients, sediments, and other pollutants to streams. They also provide local benefits of shade, overhead cover, leaf litter to feed the aquatic food web, and large woody debris, which in turn provides cover and forms pool and riffle microhabitats (Karr and Schlosser 1978, Gregory et al. 1991). Removal of riparian vegetation can increase stream temperatures, often with adverse effects on stream fish (Barton et al. 1985). The loss of watershed or riparian vegetation increases the potential for overland and channel erosion, often increasing the siltation of stream bottoms and obliterating the clean gravel surfaces used by many fish species as spawning habitat (Berkman and Rabeni 1987). Stream bottoms that become embedded with increased sediment loads provide less habitat for many benthic macroinvertebrates. Stream channelization alters runoff patterns and creates "flashy" streams with more extreme high and low flows, increased scouring, and streambank erosion. These altered flows accelerate downcutting and widening of stream channels. This increased hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a watershed and causes higher overland flows to streams, especially during storm events. Streams with highly altered flow regimes often become wide, shallow, and homogeneous, resulting in poor habitat for many fish species (Schlosser 1991). Concrete-lined streams are perhaps the most severe example of habitat loss for fish, benthic macroinvertebrates, and other aquatic animals.

The Survey collects physical habitat data for streams throughout the State, following methods largely adapted from other national and regional protocols (Plafkin et al. 1989, Barbour and Stribling 1991, Ohio EPA 1987, Rankin 1989; see Chapter 2 for details). It provides estimates, on a basinwide and statewide scale, of the extent and types of stream habitat degradation occurring in Maryland streams. In addition, the recently-developed Physical Habitat Index (PHI) can be used to assess the extent of stream habitat in various conditions. Analyses using the data from the 1995-1997 MBSS were conducted to identify key physical habitat parameters that may affect fish and benthic macroinvertebrate communities. Associations between the PHI and biological communities are also presented below.

7.2 EVALUATION OF PHYSICAL HABITAT DEGRADATION USING INDIVIDUAL PARAMETERS

A key question of interest to stream managers is: To what extent are Maryland streams affected by various types of physical habitat degradation? For example, what percentage of stream miles have low instream habitat quality, poor riparian buffers, or other evidence of degradation? Current MBSS results provide statewide estimates from data collected between 1995 and 1997. Statewide physical habitat assessment results (percentage of stream miles in each class for a series of factors) are presented in Appendix D (Table D-1); highlights for the following parameters are presented below: riparian vegetation, stream alteration, bank erosion potential, instream condition, aesthetic quality and remoteness, and quantity of available physical habitat.

7.2.1 Riparian Vegetation

A complete characterization of stream habitat goes beyond in-channel measures and includes the riparian zone adjacent to the stream. The effectiveness of the riparian buffer in mitigating nutrient loading and providing other benefits to the stream (described above) varies with the type and amount of riparian vegetation. MBSS results describe both the type and extent of local riparian vegetation, estimated as the functional width of the riparian buffer along each 75-m sample segment. Statewide, an estimated 58% of stream miles had forested buffers, 14% had other kinds of vegetated buffers (wetland, old field, tall grass, or lawn), and 28%, while perhaps having some vegetation, had an effective buffer width of 0 m (this estimate was based on sites where no buffer was present or where an outfall pipe was observed, draining directly into the stream segment). An estimated 40% of stream miles had at least a 50-m riparian buffer (Figure 7-1); about 32% had buffer vegetation less than 50 m wide. The data indicate that as buffer width increases, buffer type switches from roughly an even split between forest and other vegetation to nearly entirely forested buffer.

A statewide map (Figure 7-2) shows the distribution of riparian buffer widths observed at MBSS sites. Sites with at least a 50-m vegetated buffer were distributed throughout the state. The largest concentrations of sites with no buffer or buffer widths of less than 50-m were in the agricultural Middle Potomac basin and portions of the Baltimore-Washington corridor; other sites with less than a 50-m buffer were scattered throughout the state.

Estimates of the extent of stream miles lacking riparian buffer indicated that 28% of stream miles statewide had no buffer, while another 7% had only a vegetated buffer 1-5 m wide. The Patapsco basin had the largest percentage of poorly buffered stream miles, with 54% lacking any buffer and 11% with 1-5 m of vegetation (in 1996 sampling). Forty-seven percent of stream miles in the Middle Potomac basin were unbuffered, while another 8% had 1-5 m of vegetation. In other basins, 0 to 37% of stream miles had no riparian buffer, and 1 to 32% had only 1-5 m buffers (Figure 7-3). The problem of insufficient riparian buffer is clearly widespread throughout the State, presenting numerous opportunities for stream restoration through re-establishment of trees and other vegetation along riparian corridors. Riparian restoration efforts should be targeted to areas with the greatest potential for ecological benefit (e.g., reduced nutrient runoff, enhanced stream habitat and water quality).

7.2.2 Stream Alteration

Channelization, beaver dams, and artificial stream blockages can also affect the quality and availability of stream habitat. Beaver dams can flood large areas, dramatically changing stream character. Dams alter upstream areas by converting lotic stream habitat to lentic (ponded) habitat, resulting in silt deposition and increased water temperature in summer. In addition, dams, culverts, and other man-made structures pose a barrier to the movement of fish.

Over the three-year study, 57 sites were noted for having beaver ponds or being unsampleable because of beaver activity. Both types of records were used to estimate the percentage of stream miles with beaver ponds. Statewide, an estimated 4% of stream miles had beaver ponds. The areas with the greatest extent of beaver ponds were the Lower Potomac (16% of stream miles), Choptank (12% in 1997 sampling), and Chester (11%) basins (Figure 7-4).

Artificial blockages were encountered at 18 sites over the three-year study. Eight sites had dams, 1 to 3 meters high. Four dams were located in the Patapsco basin, three were located in the Gunpowder basin, and one was located in the Elk. Culverts were reported at nine sites, each creating a blockage about 1 meter high. Two were found in the Patuxent basin, and one each was found in the Patapsco, Pocomoke, Middle Potomac, Lower Potomac, Chester, and Bush basins. A less than one-meter-high gaging station weir was also reported blocking the stream at one site in the Patapsco basin.

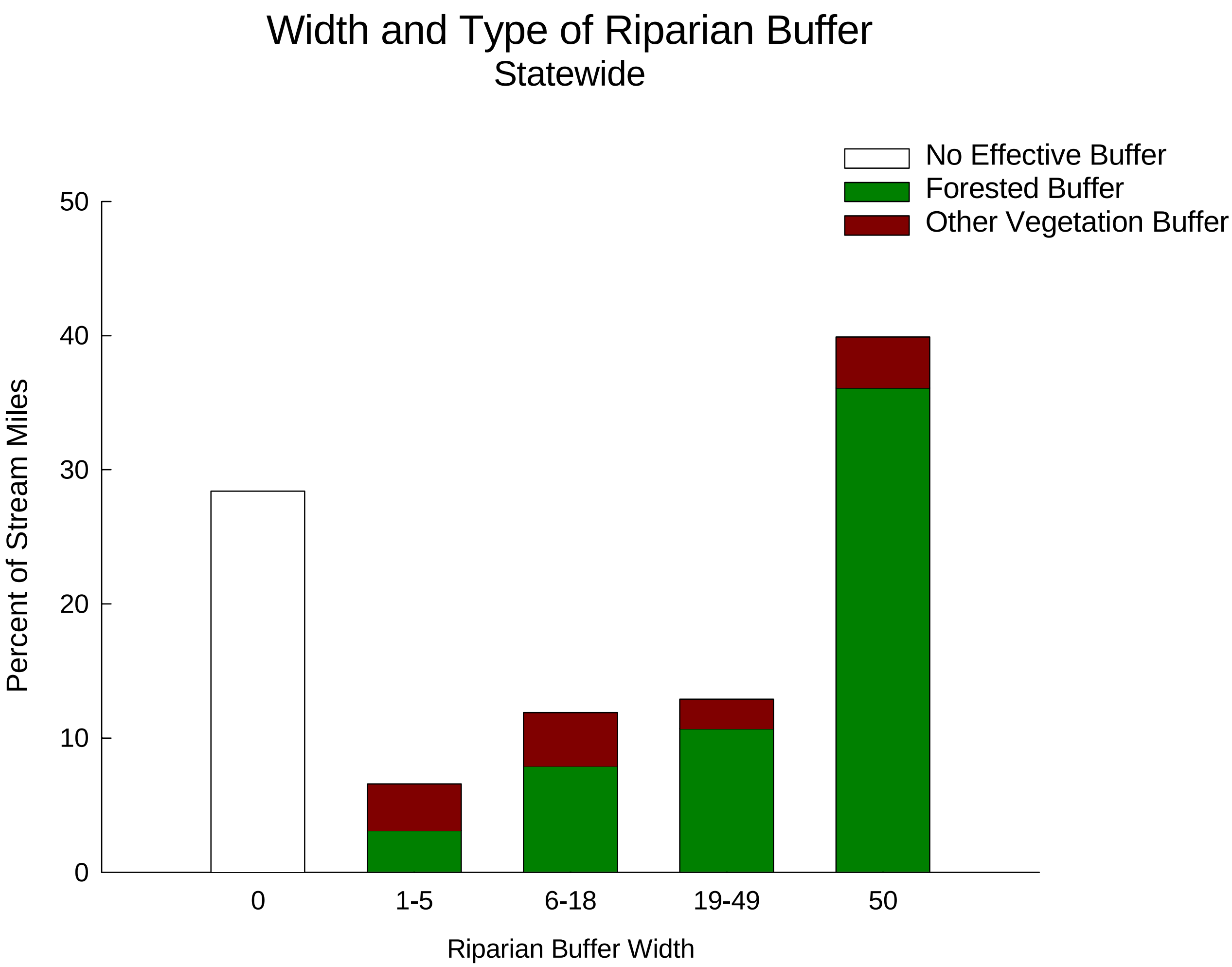

Figure 7-1. Percentage of stream miles by riparian buffer type and width for the 1995-1997 MBSS. The category "Other Vegetation Buffer" includes old field, emergent vegetation, mowed lawn, tall grass, and wetland vegetation. No effective buffer indicates that although some vegetation may be present, runoff (such as from an outfall pipe) occurs directly into the stream.

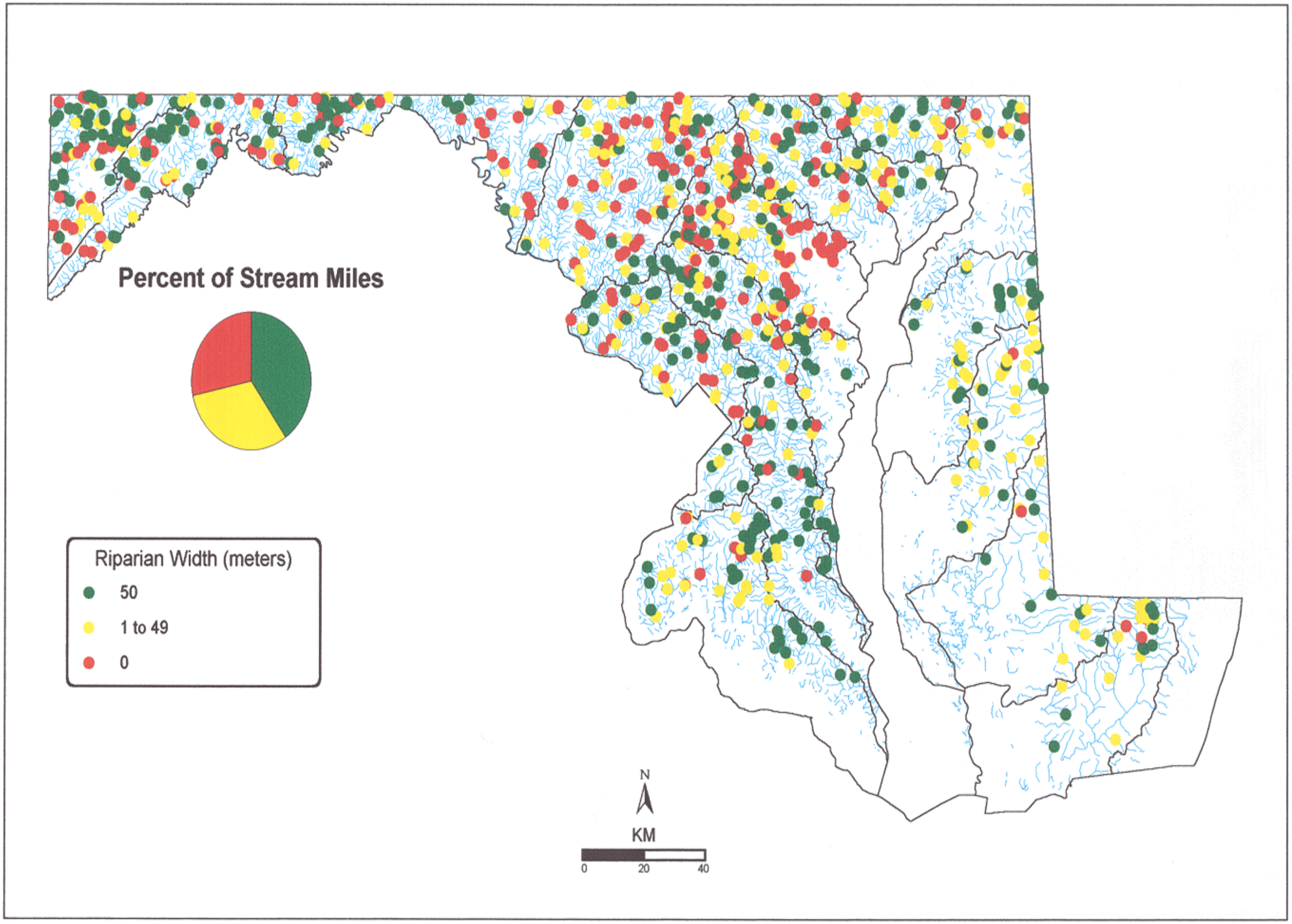

Figure 7-2. Riparian buffer width at sites sampled in the 1995-1997 MBSS. Pie chart indicates the statewide percentage of stream miles in each riparian width category.

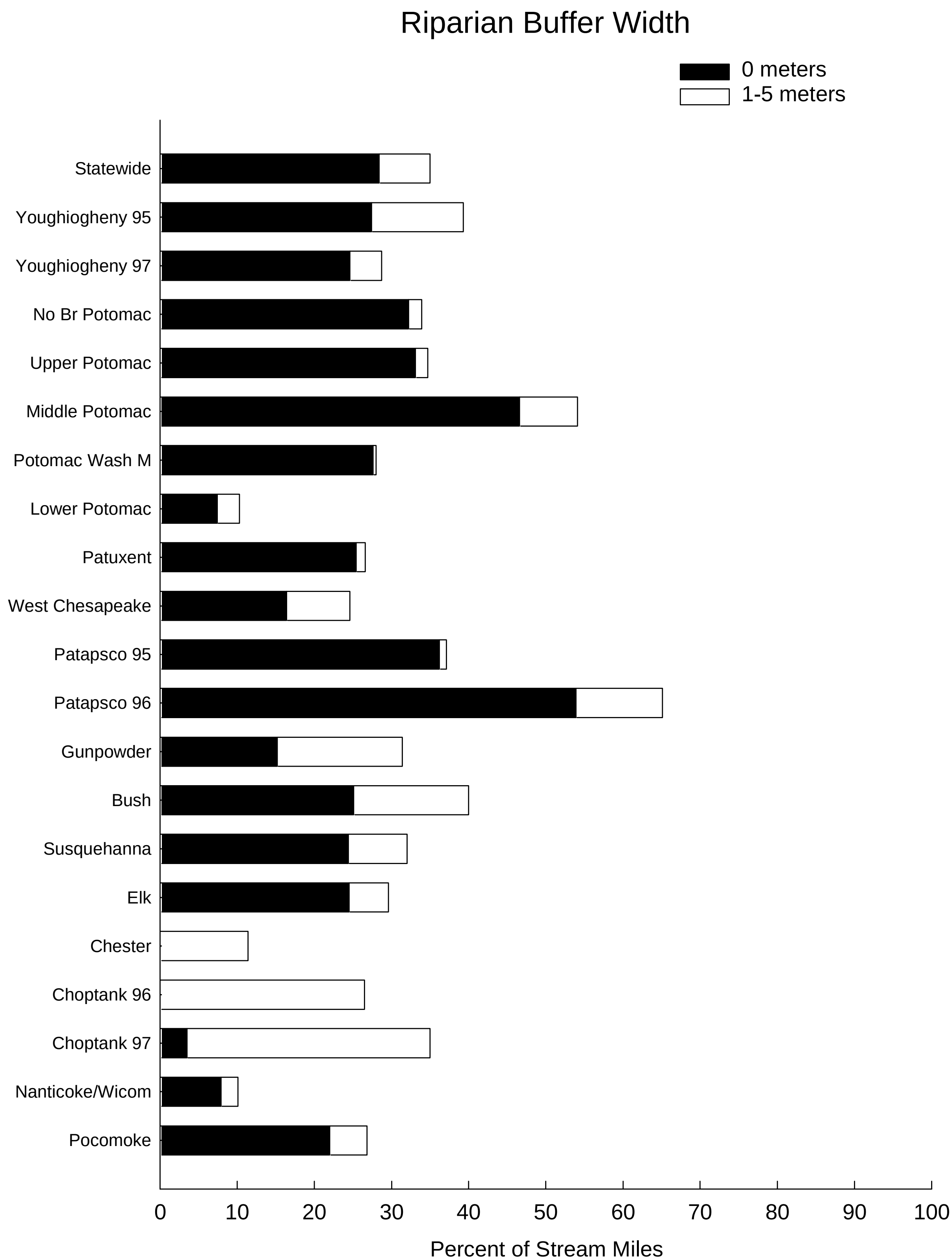

Figure 7-3. Percentage of stream miles with riparian buffer width less than 5 meters, statewide and for the basins sampled in the 1995-1997 MBSS

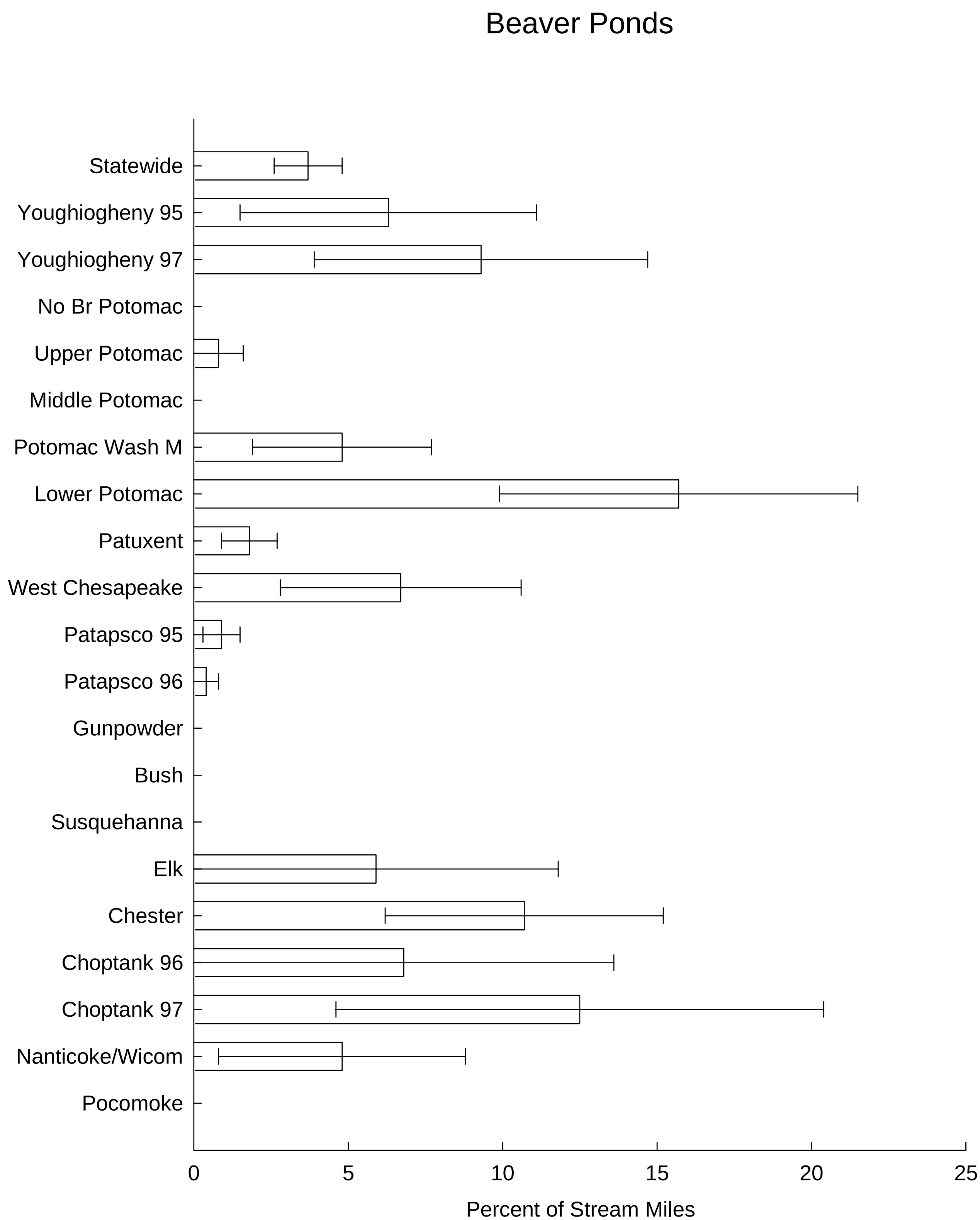

Figure 7-4. Percentage of stream miles with beaver ponds, statewide and for the basins sampled in the 1995-1997 MBSS

Channelization can also substantially alter the character of the stream. Historically, streams were commonly channelized to drain fields and to provide flood control. Today, streams in urban areas are often channelized to accommodate road-building or to drain stormwater from developed areas. When previously meandering streams are straightened, they lose their natural connection to the floodplain, with significant adverse consequences for the stream ecosystem. For example, increased flows during storm events can lead to greater scouring, greater bank instability, and disruption of the natural pattern of riffle and pool habitats. At other times, decreased baseflows can result in stagnant ditches with substrates degraded by heavy sediment deposition. MBSS results indicate that stream channelization is widespread in Maryland. Statewide, an estimated 17% of stream miles are channelized. The greatest extent of channelization was observed in the Pocomoke (81% of stream miles), Nanticoke/Wicomico (52%), Chester (44%), Patapsco (38% in 1996 sampling) and Choptank (38% in 1997 sampling) basins (Figure 7-5).

7.2.3 Bank Erosion Potential

Field assessments of several factors related to bank erosion potential were made at each site sampled in the 1995-1997 MBSS. Using a standard set of criteria to categorize observations (Rosgen 1996), field crews collected data on five stream bank erodibility factors, as follows:

- Bank height to bankfull height (the ratio of streambank height to bankfull stage);
- Bank angle (the slope of the streambank);
- Bank root coverage (the amount of bank surface protection given by roots and other woody debris, rooting density, and ratio of riparian vegetation rooting depth to streambank height);
- Soil stratification (bank material stratigraphy and presence of soil lenses); and
- Particle size (the composition of streambank materials).

Each of these five individual factors was assigned a rating based on criteria and diagrams from Rosgen (1996). The original classification system of low, moderate, and high bank erosion potential was changed to a five-point scale to allow for intermediate ratings (low-to-moderate, moderate-to-high). For each factor, a rating of 1 was most favorable (i.e., with the least potential for bank erosion and greater bank stability). A 5 was least favorable (i.e., with the highest potential for bank erosion and the least stable bank conditions). A rating of 3 indicated moderate bank erosion potential and fair bank stability conditions.

To obtain an overall erosion potential score for each site, the scores for bank height to bankfull height, bank angle, and bank root coverage were summed together, giving a possible range of 3 to 15. Statewide and basin-specific estimates of the percentage of stream miles in each of the following categories were calculated:

- Lowest potential for erosion: $3 \leq$ Erodibility index ≤ 6
- Low potential for erosion: $6 <$ Erodibility index ≤ 9
- High potential for erosion: $9 <$ Erodibility index ≤ 12
- Highest potential for erosion: $12 <$ Erodibility index ≤ 15

Statewide, 35% of stream miles had high potential and 7% of stream miles had highest potential for erosion, according to this index. Another 35% had low potential and 22% had lowest potential for erosion. Basins with the most extensive erosion potential included the Patuxent (total of 87% of stream miles with high or highest potential for erosion), Elk (69%), Bush (64%), Pocomoke (59%), and Patapsco (58% in 1996 sampling) (Figure 7-6). The Pocomoke basin had the greatest percentage of stream miles in the highest erosion potential category (35%).

7.2.4 Instream Condition

A number of parameters describing the habitat condition within the stream channel were qualitatively assessed at each sample site. Ratings of 0-20 were assigned to each of five parameters: instream habitat structure, epifaunal substrate, velocity/depth diversity, pool/glide/eddy quality, and riffle/run quality. Scores for each of these parameters were grouped by the four scoring categories used in field observations: poor (1-5 points), marginal (6-10), sub-optimal (11-15), and optimal (16-20). For each parameter, the percentage of stream miles in each basin with low-scoring (poor to marginal) habitat is shown in Figures 7-7 to 7-11. Low scores are generally indicative of conditions less able to support biological communities; such scores represent areas of degradation. An accurate determination of whether a score represents degradation by human activities depends on what score is expected under natural conditions (as found in minimally impacted reference streams). Reference conditions vary geographically; for example, a riffle/run quality score for an unimpacted, stream

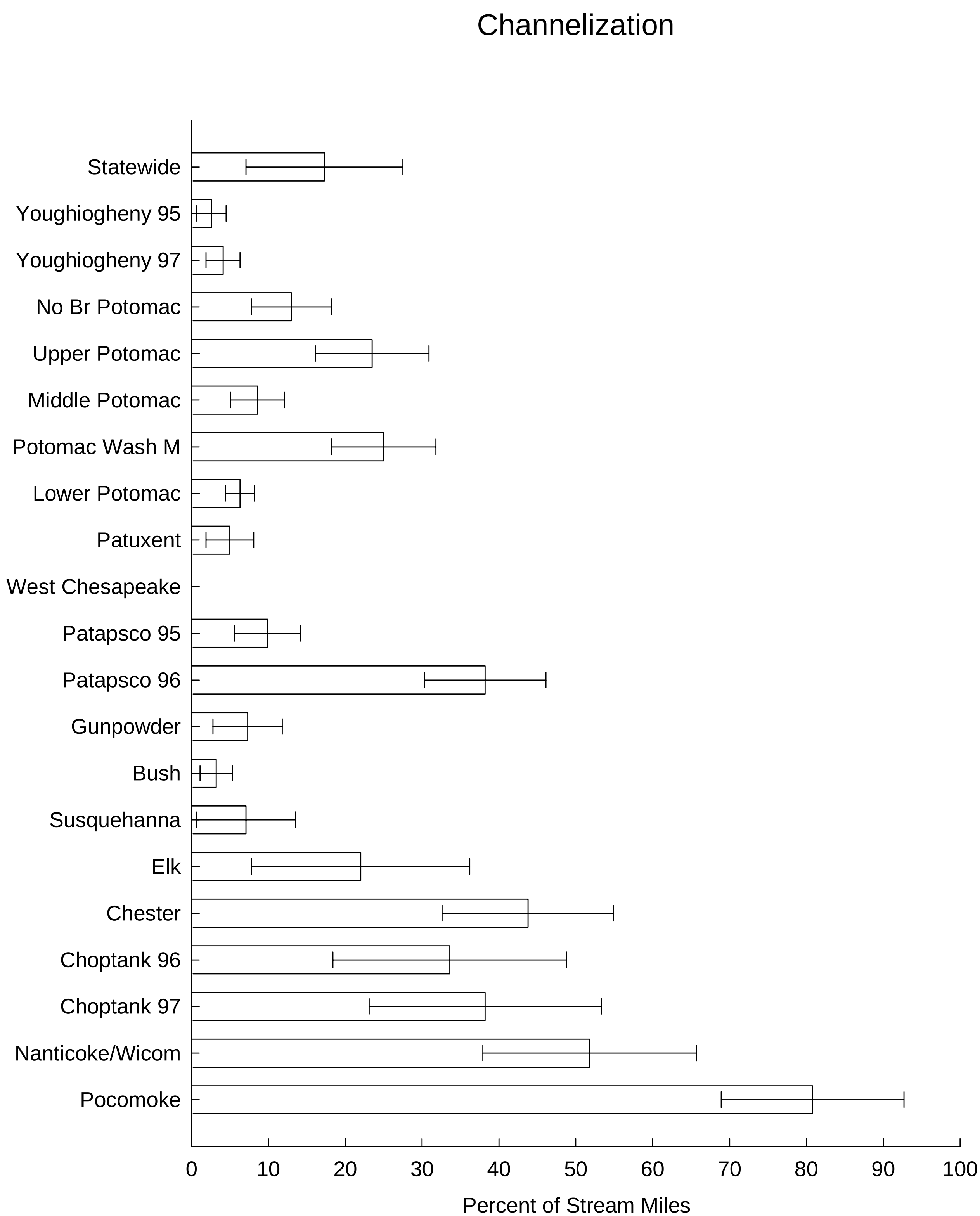

Figure 7-5. Percentage of stream miles with evidence of channelization, statewide and for the basins sampled in the 1995-1997 MBSS

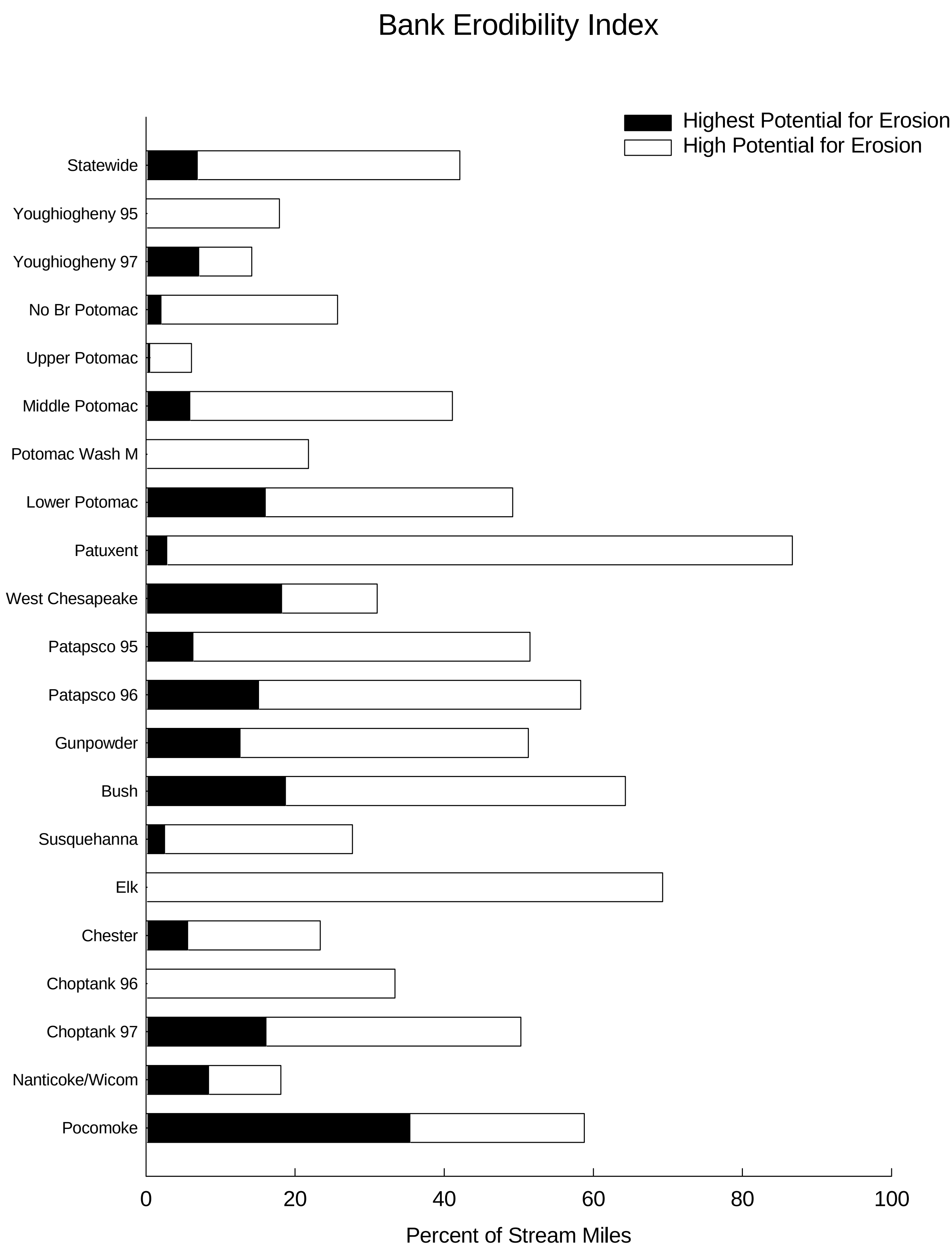

Figure 7-6. Percentage of stream miles in "Highest" and "High" categories of the bank erodibility index, statewide and for the basins sampled in the 1995-1997 MBSS

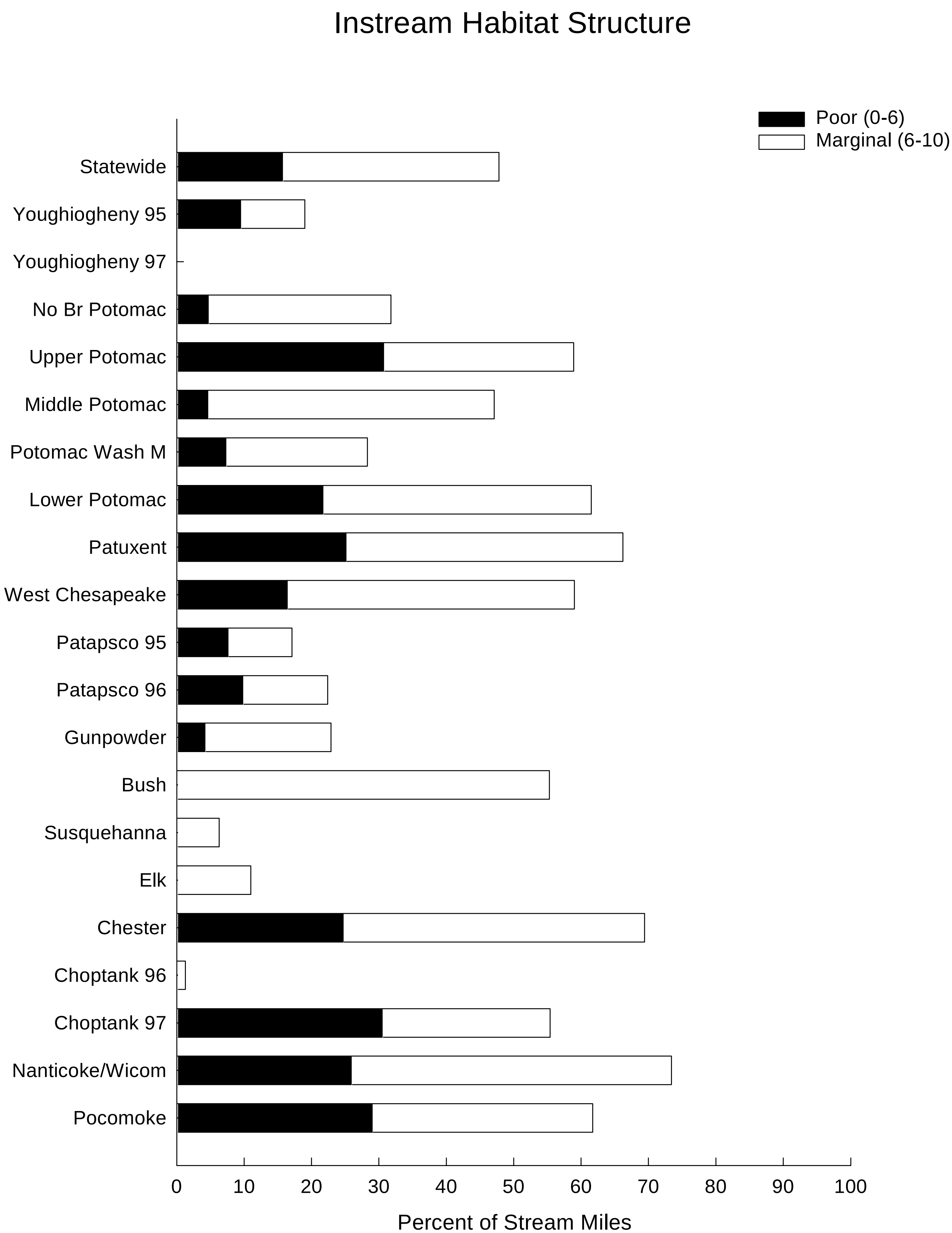

Figure 7-7. Percentage of stream miles with poor and marginal instream habitat structure, statewide and for the basins sampled in the 1995-1997 MBSS

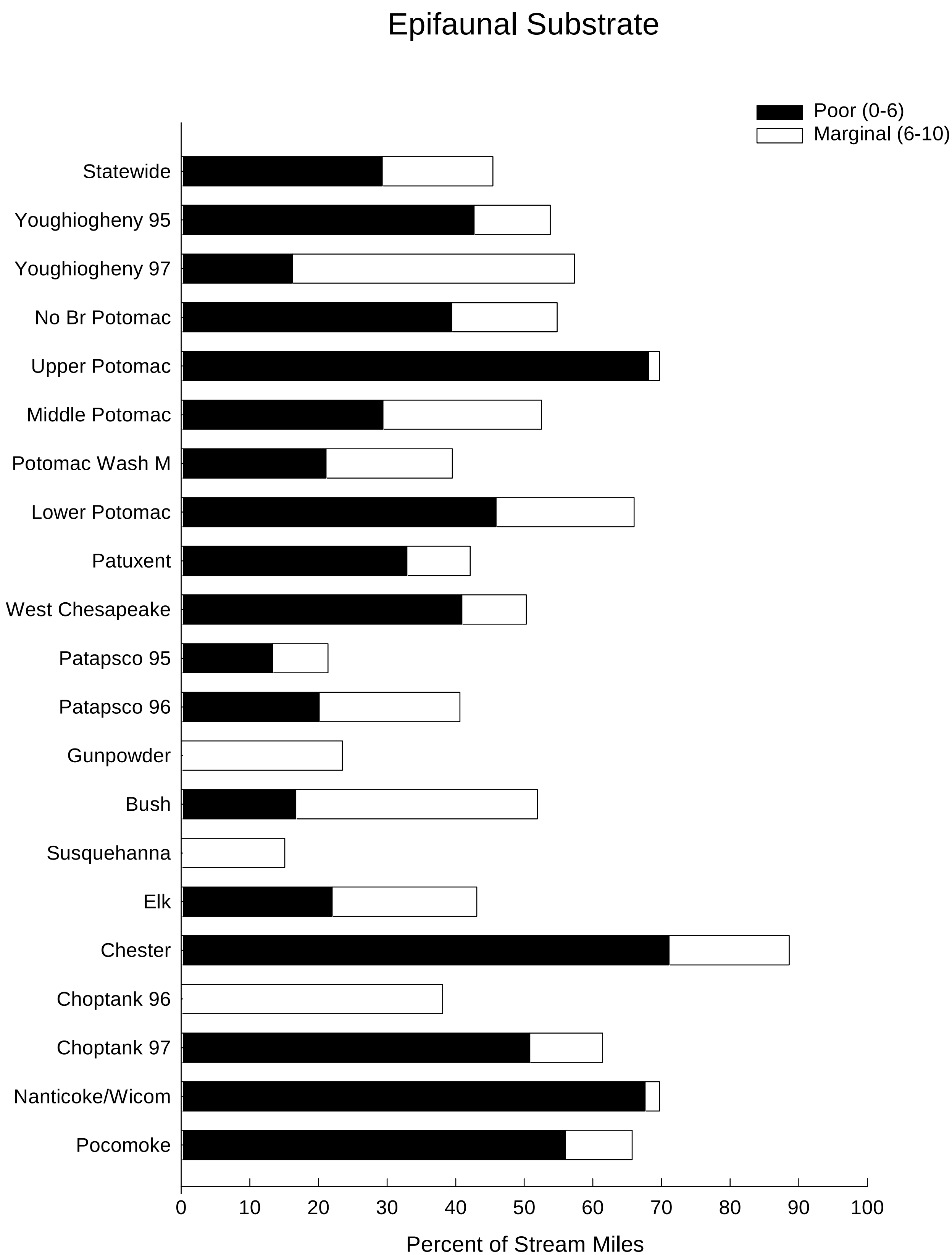

Figure 7-8. Percentage of stream miles with poor and marginal epifaunal substrate, statewide and for the basins sampled in he 1995-1997 MBSS

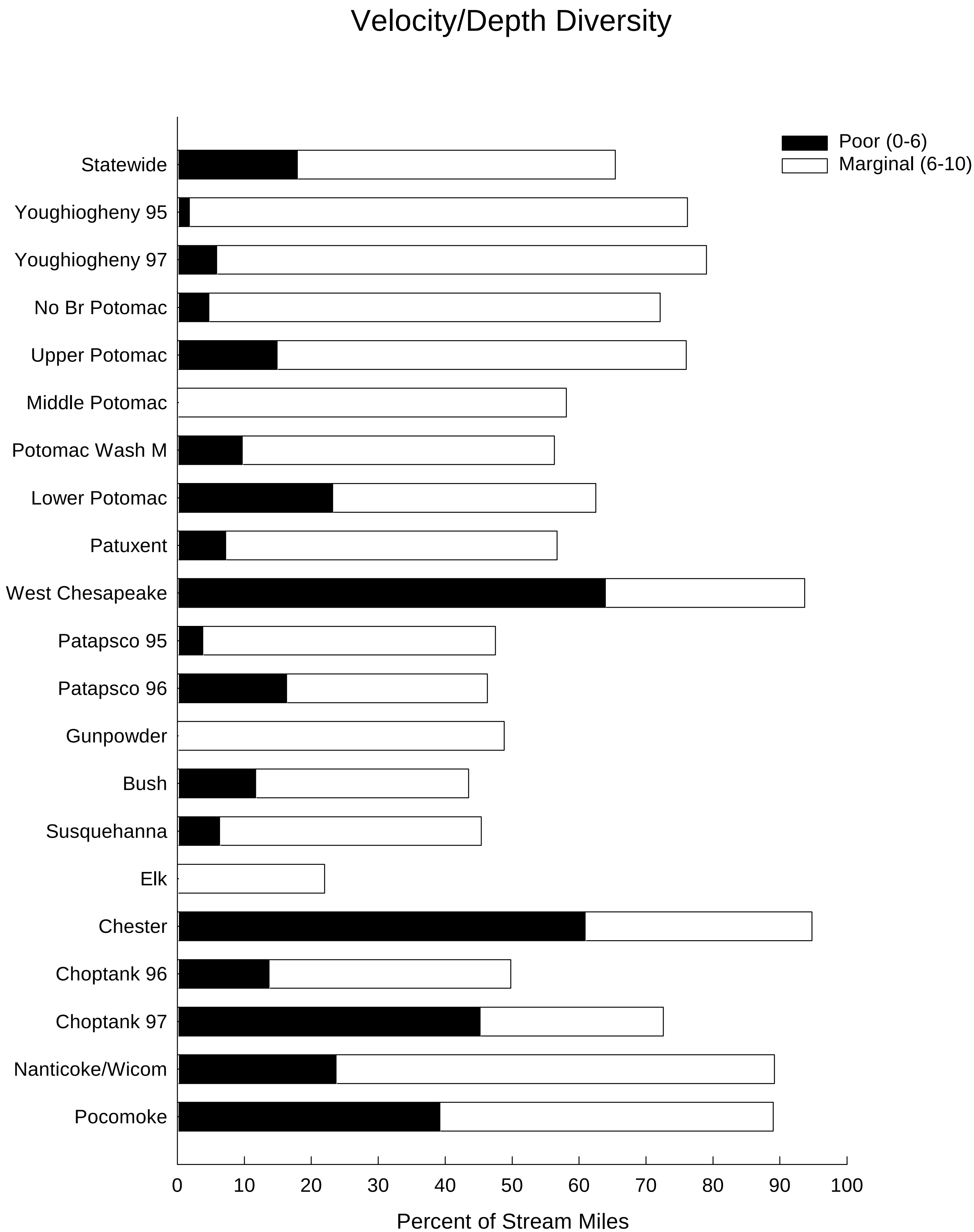

Figure 7-9. Percentage of stream miles with poor and marginal velocity/depth diversity, statewide and for the basins sampled in the 1995-1997 MBSS

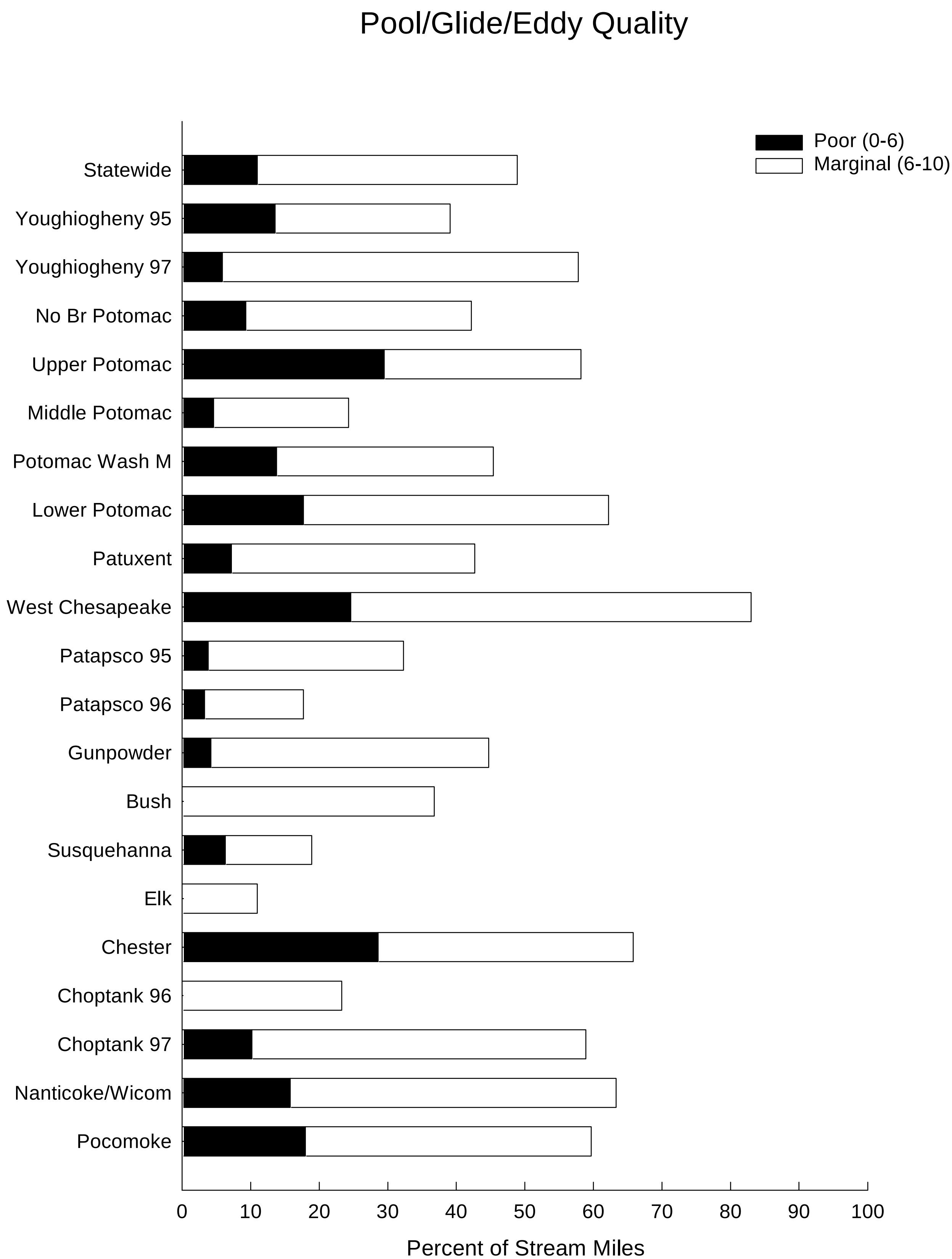

Figure 7-10. Percentage of stream miles with poor and marginal pool/glide/eddy quality, statewide and for the basins sampled in the 1995-1997 MBSS

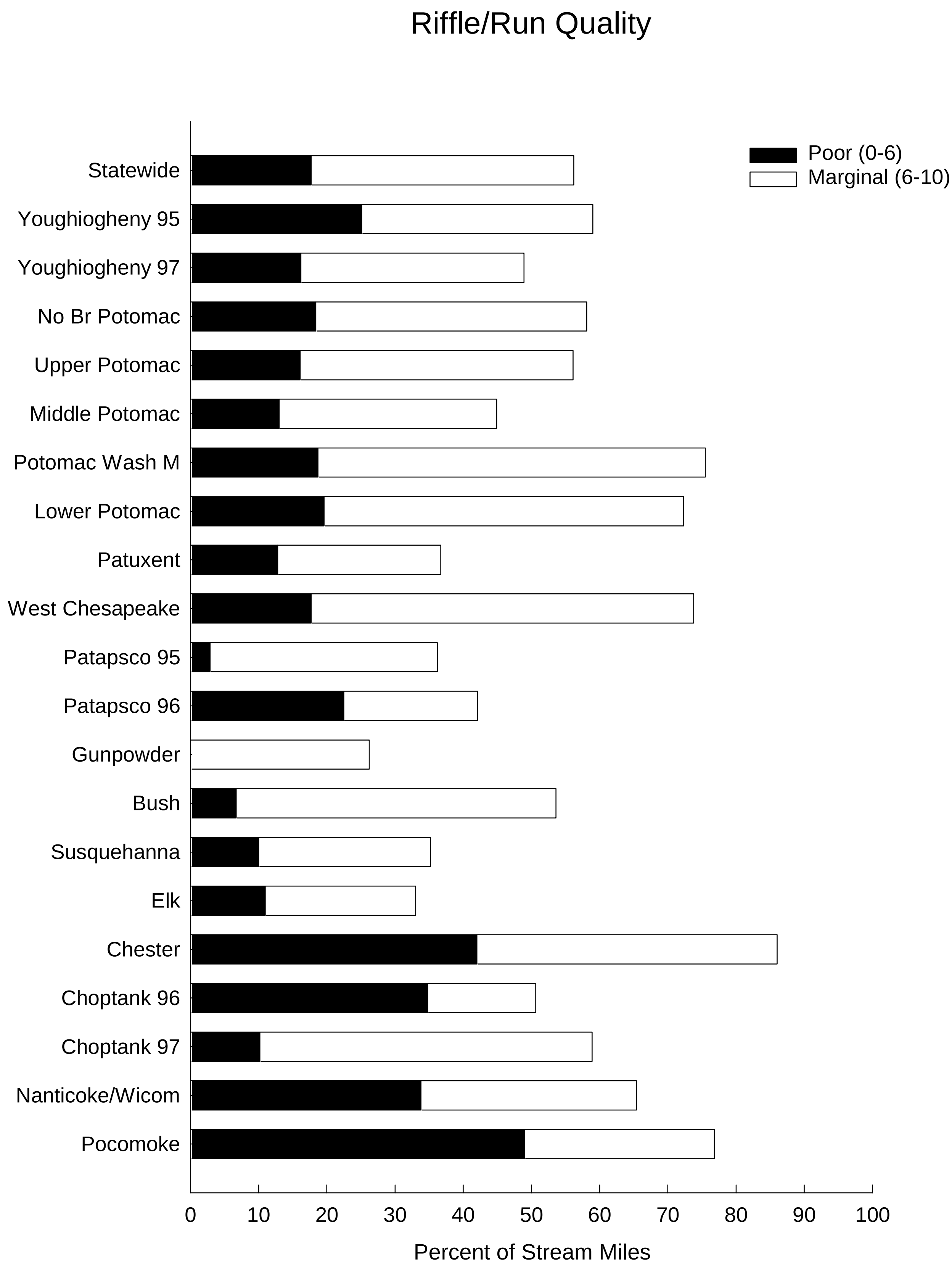

Figure 7-11. Percentage of stream miles with poor and marginal riffle/run quality, statewide and for the basins sampled in the 1995-1997 MBSS

in the Coastal Plain may be lower than for an unimpacted Appalachian stream, because Coastal Plain streams typically are lower gradient and lack cobble/gravel substrates. These comparisons are further complicated by uncertainty about what natural Coastal Plain streams were like prior to European settlement.

The instream habitat structure parameter represents the amount of stable habitat structure in a stream, i.e., cobbles, boulders, logs, undercut banks, rootwads, aquatic plants, and other materials providing habitat and cover for fish. Statewide, a modest percentage of stream miles had either poor (12%) or marginal (28%) instream habitat structure, while 22% were rated as optimal and 38% as suboptimal. Among the basins, the greatest proportions of poor to marginal instream habitat structure (Figure 7-7) were found in the Nanticoke/Wicomico, Chester, and Patuxent basins, where 74, 70, and 66% of stream miles, respectively, fell within this range. In contrast, the Youghiogheny (1997 sampling) had no poor or marginal areas of instream habitat and the Choptank (1996 sampling), Susquehanna, and Elk basins had no poor areas and only 1, 6, and 11% of their respective stream miles listed as marginal. The Bush basin also had no poor-rated habitat, but had 55% marginal instream habitat structure.

Epifaunal substrate is based on the amount and variety of hard stable substrates available to benthic macroinvertebrates (i.e., substrates free of fine sediments or flocculent material). Statewide, nearly half of the stream miles had poor (31%) to marginal (17%) epifaunal substrate (Figure 7-8). The Chester basin had the greatest proportion of poor to marginal epifaunal substrate stream miles (88%). The Nanticoke/Wicomico, Upper Potomac, Lower Potomac, and Pocomoke had poor to marginal epifaunal substrate in greater than 65% of stream miles. Conversely, the Gunpowder and Susquehanna basins had no poor epifaunal substrate and 24% and 15% stream miles of marginal epifaunal substrate, respectively. Low scores for epifaunal substrate may indicate erosion and sedimentation.

Velocity/depth diversity assesses the variety of velocity and depth regimes in the stream segment (slow-shallow, slow-deep, fast-shallow, and fast-deep) and reflects the heterogeneity of available riffle and pool microhabitats. Statewide, poor conditions were present in 12% of the stream miles, while marginal conditions were more common, occurring in 48% of the stream miles (Figure 7-9). Four basins, the Chester (95%), West Chesapeake (94%), Nanticoke/Wicomico (89%), and Pocomoke (89%), each had at least 85% of their stream miles with poor to marginal velocity/depth diversity. Two of these basins, West Chesapeake (64%) and Chester (61%), had poor velocity depth diversity in greater than 60% of their stream miles. The Elk basin had the smallest percentage of stream miles in poor to marginal velocity/depth diversity categories, with no poor stream miles and only 22% marginal. Two other basins had no poor stream miles. Both basins had approximately half their stream miles marginal with 58% and 49%, respectively.

Pool/glide/eddy quality represents the variety, extent, and spatial complexity of slow- or still-water habitat available. Pool/glide/eddy quality, shown in Figure 7-10, was rated as poor in 10% and marginal in 31% of stream miles, statewide. One basin, the West Chesapeake, had 83% of stream miles rated as poor to marginal. Seven other basins had between 58% and 65% poor to marginal pool/glide/eddy quality. Two basins, the Elk and the Choptank (1996 sampling) had no poor and only 11% and 25% marginal pool/glide/eddy quality, respectively.

Riffle/run quality is based on the depth, complexity, and functional importance of riffle and run habitat within the sampled segment. According to statewide estimates, riffle/run quality was poor in 16% of stream miles and marginal in 34% (Figure 7-11). The Chester basin had the greatest proportion of poor to marginal riffle/run quality stream miles (83%). Not surprisingly, low riffle/run quality scores were common in the Chester and other coastal plain basins where riffles are naturally less frequent.

Instream condition scores varied with stream size for many of these parameters. Compared to second- and third-order streams, first-order streams tended to receive lower scores for instream habitat structure, epifaunal substrate, velocity/depth diversity, pool/glide/eddy quality, riffle/run quality, as well as channel alteration. This may indicate that first order streams are more degraded, possibly because they are smaller and therefore more sensitive to anthropogenic stress. However, habitat conditions vary with stream size (Vannote et al. 1980), so differences among stream orders are expected. To accommodate for this natural variability, scoring for first-order streams should be adjusted for the different expectations of small stream habitats using more appropriate reference conditions for different stream sizes (as done for geographic regions in the Physical Habitat Index described in Section 7.3.1).

7.2.5 Aesthetic Quality and Remoteness

Aesthetic quality and remoteness are additional components of stream character rated by the Survey. These are assessed (on a 0-20 point scale) by observing the area surrounding each sampled stream segment. Although these components may not directly affect stream biota, they reflect important human values associated with streams. Aesthetic quality characterizes the visual appeal of a site and declines with visible signs of human impact such as trash. Statewide, an estimated 43% of the stream miles were aesthetically pleasing (scoring $\geq$ 16 out of 20). Only 10% were rated as poor and 17% as marginal (Figure 7-12). By basin, the Choptank (5% in 1997 sampling), Gunpowder (11%), and Youghiogheny (11% in 1997 sampling) had the fewest percentage of stream miles rated poor to marginal for aesthetic quality. The Patapsco (56% in 1996 sampling), West Chesapeake (54%), and Nanticoke/Wicomico (50%) basins had the greatest percent stream miles rated poor to marginal.

Remoteness scores were based on a combination of three factors: the distance from the site to the nearest road, accessibility, and evidence of human activity. Over all basins sampled, 17% of the stream miles were difficult to access (scoring $\geq$ 16 out of 20). Twenty-eight percent were rated as moderately easy to access and 29% as easy access (Figure 7-13). The Elk (85%), Potomac Washington Metro (77%), and Patapsco (78% in 1996 sampling) had the greatest percentage of stream miles rated as easy or moderately easy to access. The North Branch Potomac (33%), Choptank (37%) in 1996 sampling, and Lower Potomac (38%) had the fewest stream miles rated as easy or moderately easy to access.

In general, aesthetic quality and remoteness ratings were positively correlated ($p < 0.0001$, $r^2=0.28$; Figure 7-14). This correlation is not surprising, given that the more difficult a site is to access, the less likely it will show signs of human disturbance.

7.2.6 Quantity of Available Physical Habitat

In addition to varying in habitat quality, streams may differ simply in the amount of physical habitat available to aquatic organisms. Larger streams naturally provide more riffles, pools, and other desirable habitat locations for fish to use for spawning, feeding, and shelter. Conversely, small streams with plentiful shallow riffle habitat may support a greater density and diversity of benthic invertebrates. Although the sites sampled in the Survey were all wadeable streams, they did vary in size from small streams (as shallow as 6 cm and less than 1 meter across) to much larger streams (as deep as 2 meters and more than 20 meters across). Several field measures of stream habitat quantity were made during the 1995-1997 MBSS to compare these differences.

Data on wetted width, average thalweg depth, discharge, and the number of pieces of woody debris and rootwads were collected in each stream segment and summarized in statewide and basin estimates. These data represent conditions throughout first-, second-, and third-order streams, but may not fully characterize the population of all streams in a single basin, particularly in basins with small sample size.

Mean stream width ranged from 2.3 m at first-order streams to 8.8 m at third-order streams. Mean stream width in most basins was between 2 and 5 m, with statewide mean of 3.4 m. Exceptions were the Elk (mean 7.8 m), Bush (5.8 m) and West Chesapeake (1.6 m) basins (Figure 7-15).

Mean thalweg depth (the depth at the deepest part of the channel, measured at four cross-sections per sampled segment) ranged from 16.8 cm in first-order streams to 41.8 cm in third-order. Streams in the western Maryland basins (Youghiogheny, North Branch Potomac, and Upper Potomac) were shallower on average than the statewide mean of 21.9 cm (Figure 7-16). Streams sampled in the Elk basin were the deepest (41.3 cm), while West Chesapeake streams were the shallowest (13.4 cm).

Stream discharge is another measure of stream size, as discharge tends to increase with watershed area, stream width, and depth. Although the Survey collected only one-time discharge data, these data provide a useful comparison of conditions across a large number of sites. Statewide, mean discharge was 2.7 cfs (cubic feet per second). First-order streams sampled had a mean discharge of 0.8 cfs, second-order 4.5 cfs, and third-order 12.6 cfs. Streams in the Elk basin exhibited the highest mean discharge (13.3 cfs), and Chester basin the lowest (0.4 cfs) (Figure 7-17).

Rootwads and other types of woody debris provide habitat, cover, and shade for a variety of stream biota. When riparian forests are removed, this important source of woody debris is lost. To assess the availability of this habitat feature, the numbers of rootwads and other woody debris within each 75-m segment were recorded by MBSS field crews. Statewide, the mean number of wood pieces per segment was about 4. The greatest amount was found in the Chester basin (10.3); other Eastern Shore basins had mean values of at least 5 pieces per segment (Figure 7-18). The lowest mean number of pieces per segment were recorded in the Youghiogheny (1.7 in 1997 sampling), Upper Potomac (1.9), and North Branch Potomac (1.9) basins.

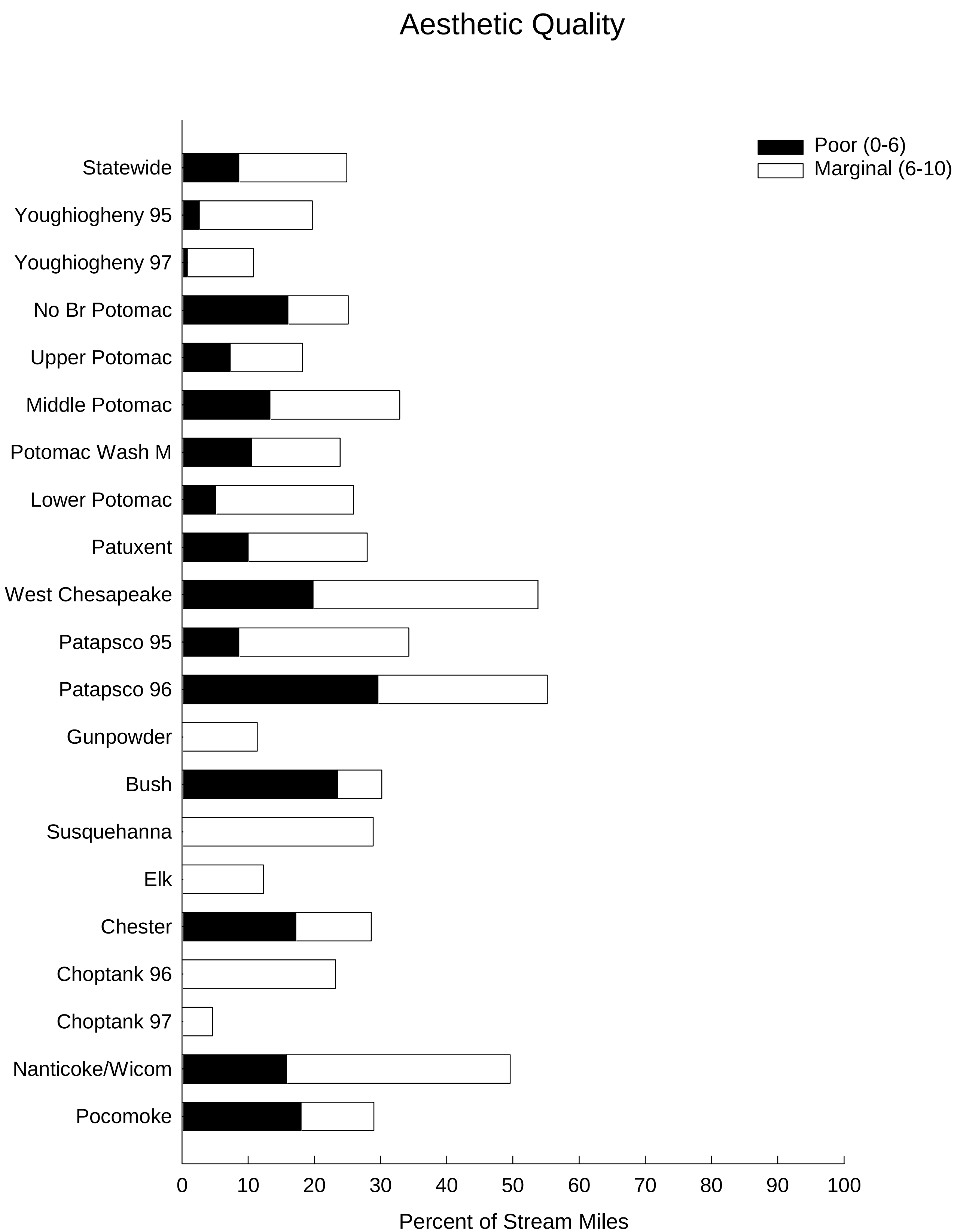

Figure 7-12. Percentage of stream miles with poor and marginal aesthetic quality, statewide and for the basins sampled in the 1995-1997 MBSS

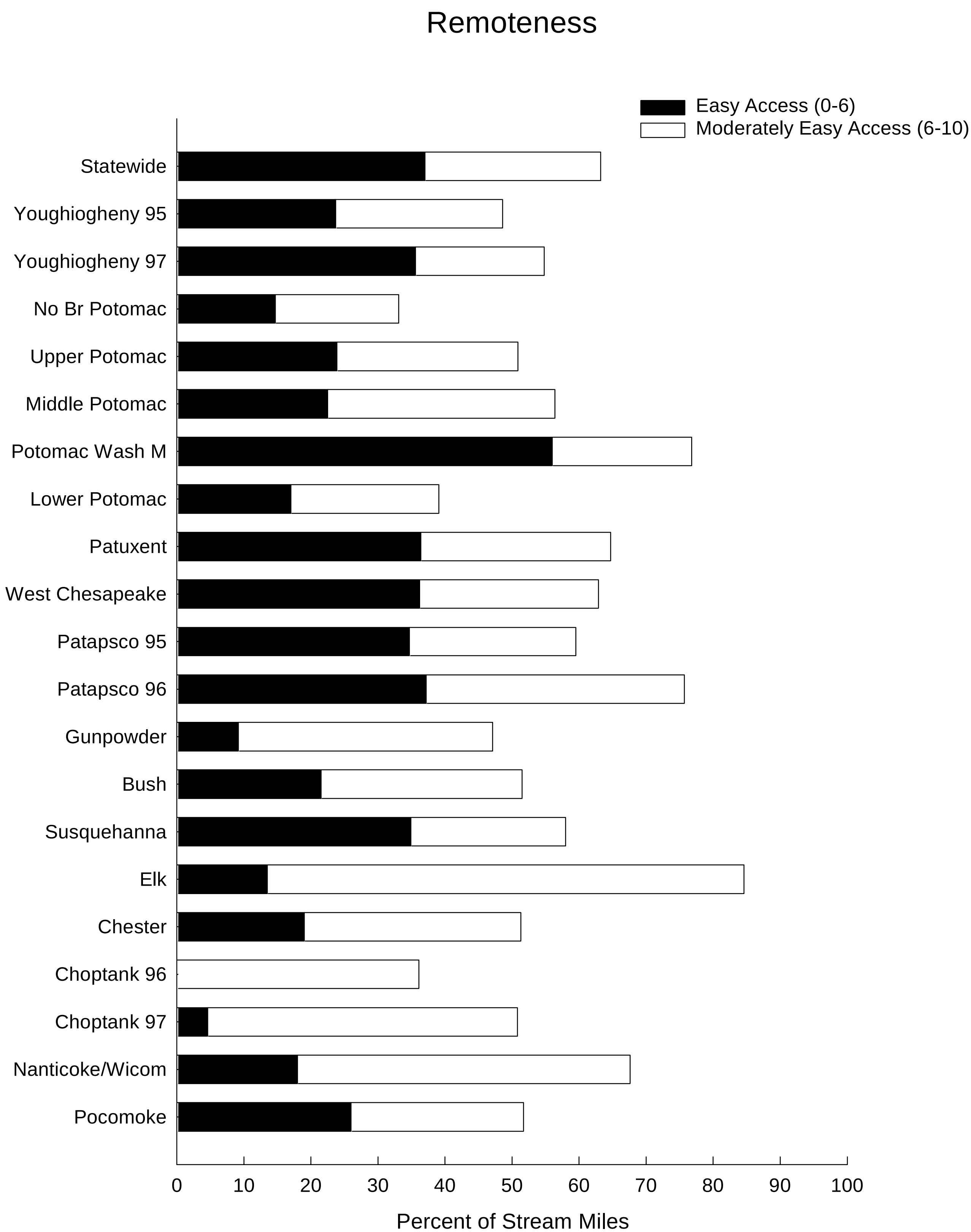

Figure 7-13. Percentage of stream miles rated as easy and moderately easy access, statewide and for the basins sampled in the 1995-1997 MBSS

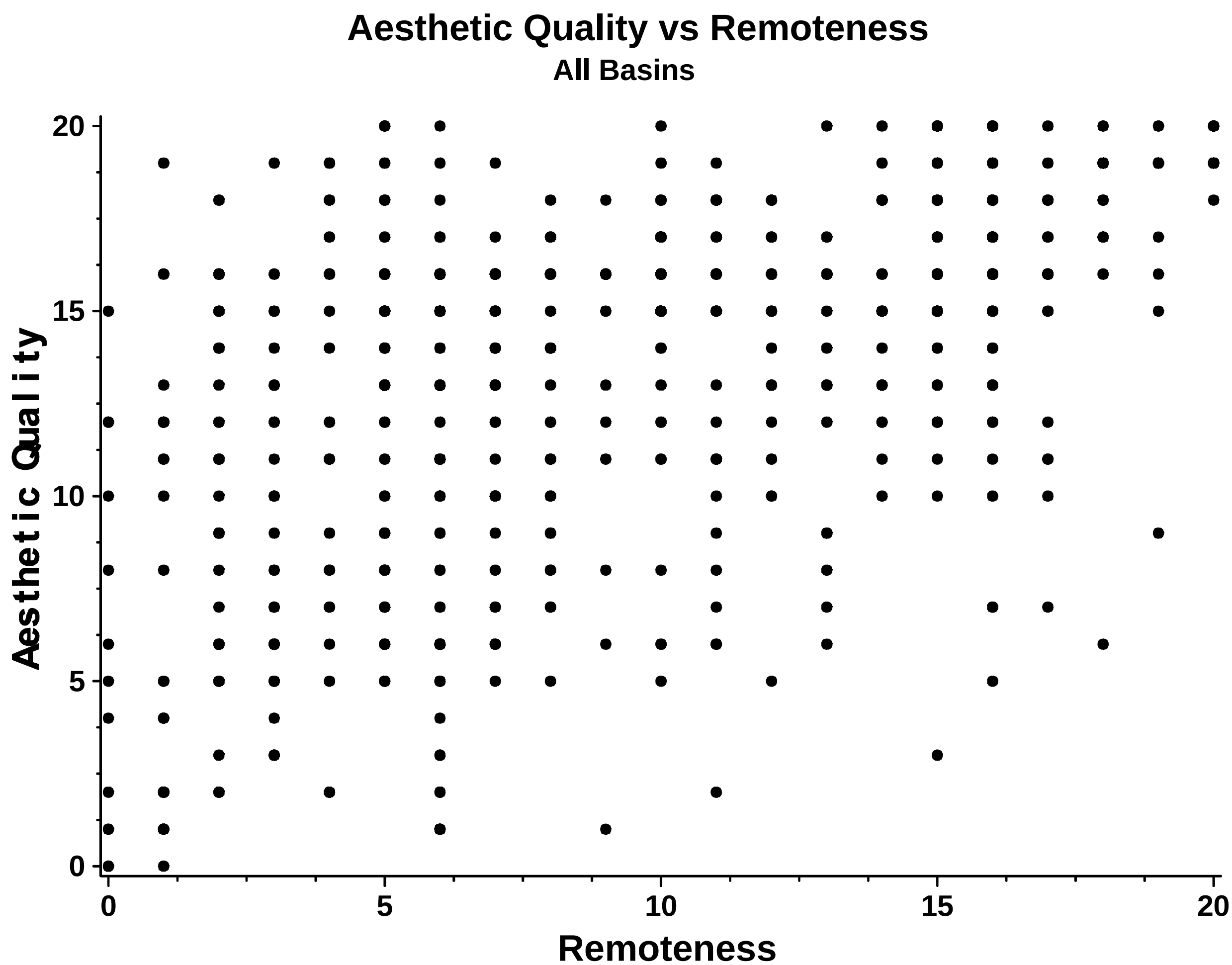

Figure 7-14. Relationship between aesthetic quality and remoteness, statewide, for the 1995-1997 MBSS

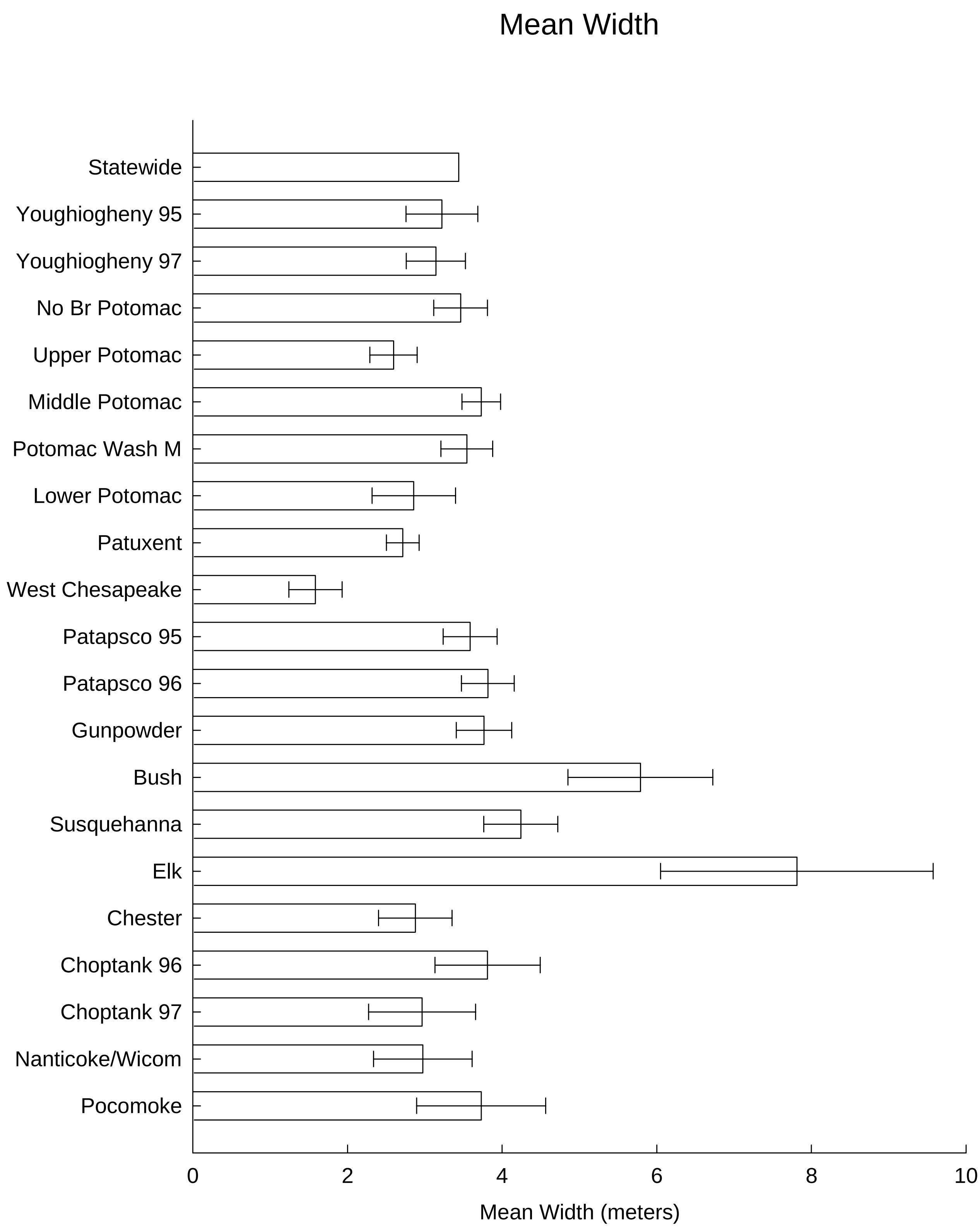

Figure 7-15. Mean stream width, statewide and for the basins sampled in the 1995-1997 MBSS (lack of error bars indicate that variance is statistically undefined)

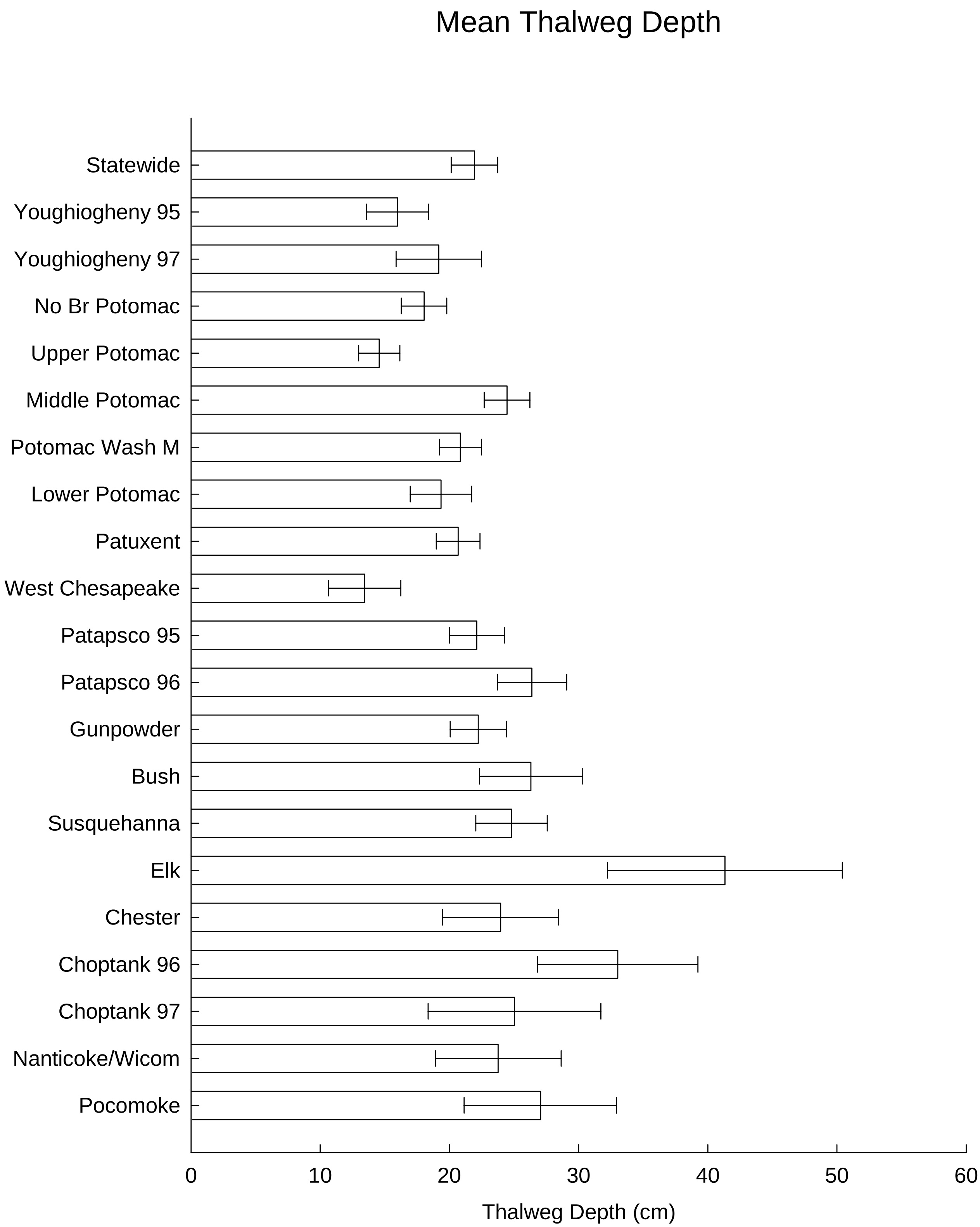

Figure 7-16. Mean thalweg depth, statewide and for the basins sampled in the 1995-1997 MBSS

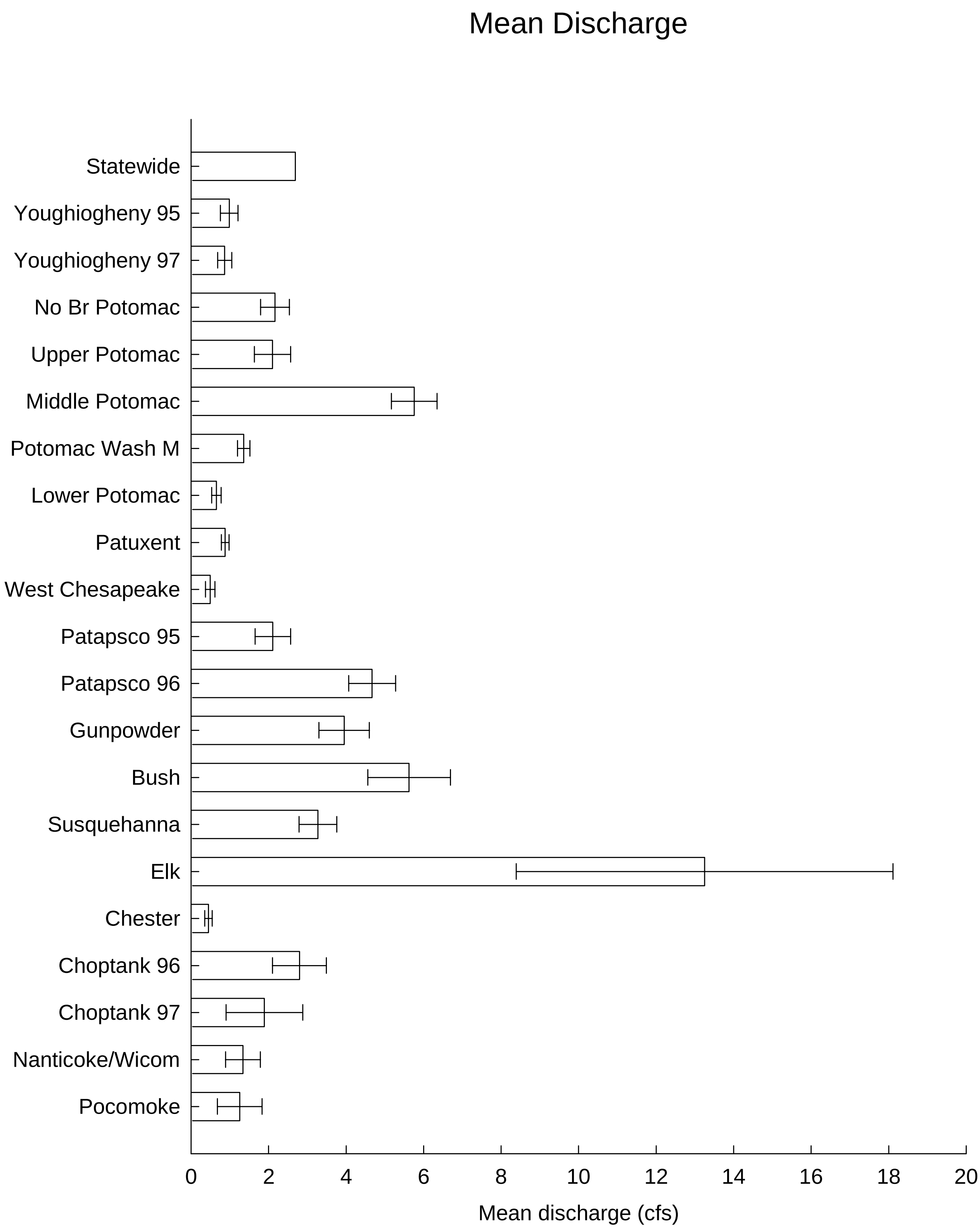

Figure 7-17. Mean discharge, statewide and for the basins sampled in the 1995-1997 MBSS (lack of error bars indicate that variance is statistically undefined)

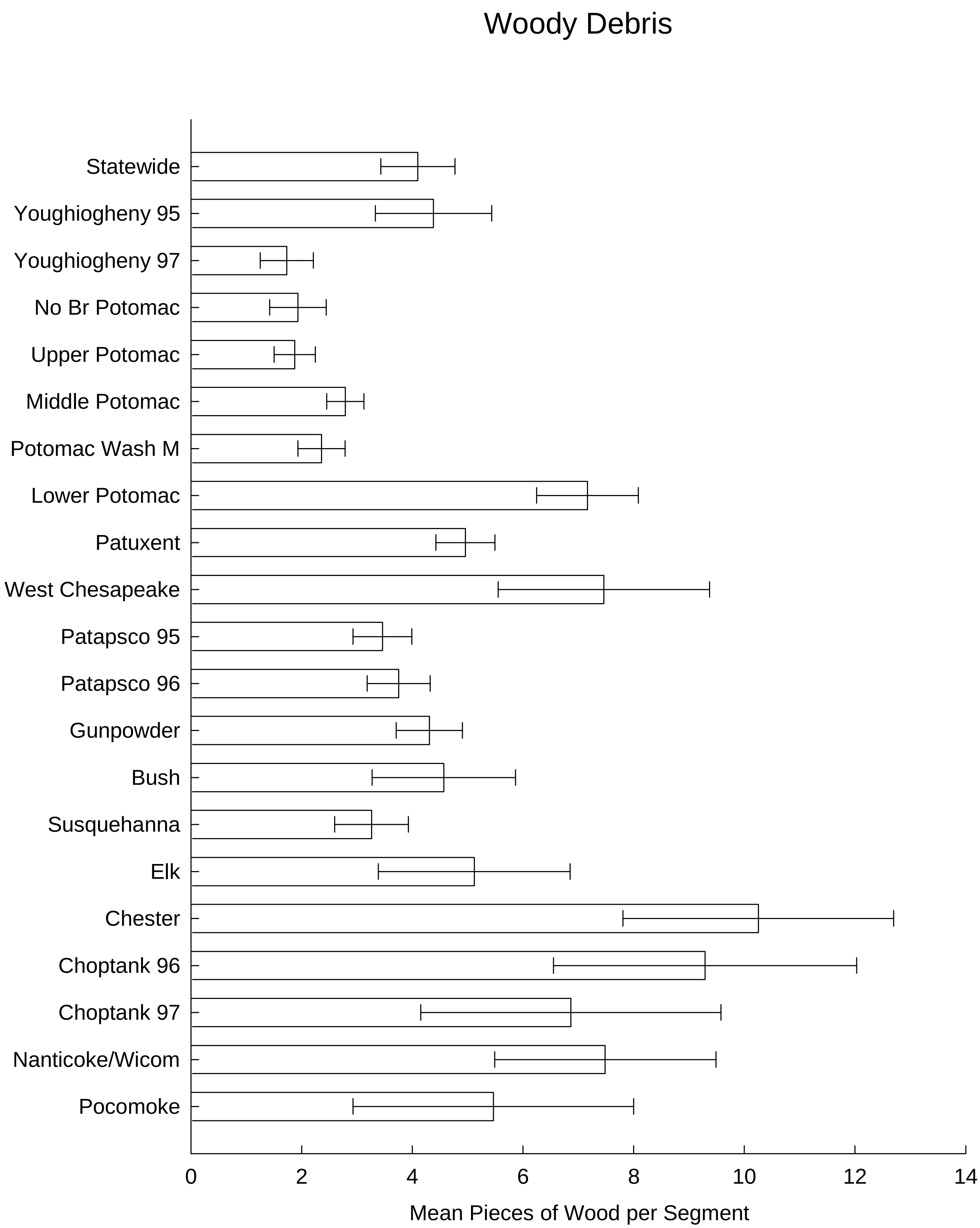

Figure 7-18. Mean number of pieces of wood found in the stream, statewide and for the basins sampled in the 1995-1997 MBSS. Number of pieces of wood includes both rootwads and large woody debris.

7.3 PHYSICAL HABITAT INDEX

The physical habitat component of freshwater streams strongly influences the composition and status of stream fish communities (Gorman and Karr 1978). Because physical habitat is such an important factor, it was assessed concurrently with fish sampling during the MBSS sampling. As described earlier, procedures for physical habitat assessment were derived from two sources: EPA's Rapid Bioassessment Protocols (RBPs) (Plafkin et al. 1989) as modified by Barbour and Stribling (1991), and the Ohio EPA's Qualitative Habitat Evaluation Index (Rankin 1989). In addition to the 13 qualitative physical habitat metrics derived from these methods, additional qualitative and quantitative stream characteristics (meandering, presence of emergent and submergent vegetation, presence of coarse woody debris, rootwad number, etc.) were recorded during MBSS field sampling. All of the measured parameters were considered in the development of a reference-based indicator of physical habitat conditions in Maryland streams.

7.3.1 Development of the Physical Habitat Index

The Physical Habitat Index (PHI) for Maryland was developed using MBSS data from 1994 to 1997 (including data from the 1994 demonstration project; Hall et al. 1999b). As was the case in development of the fish and benthic IBIs, the conceptual approach was based on evaluating the relative importance (discriminatory power) of individual metrics and combinations of metrics for explaining natural differences in streams throughout Maryland. Based on analyses conducted for both fish IBI (Roth et al. 1998) and benthic IBI (Stribling et al. 1998) development in Maryland, the State was divided into two regions: the Coastal Plain and non-Coastal Plain. These two geographic strata are consistent with aggregations of ecoregions (Omernik 1987) or physiographic provinces developed for Maryland (Reger 1995). Separate PHIs were developed for each stratum.

As was the case with the fish and benthic IBIs, the approach to developing the PHI consisted of the following five steps: (1) developing and organizing the data base, (2) scaling and evaluating the distribution of various metrics, (3) identifying reference and degraded sites, (4) assessing the discriminatory power of physical habitat metrics and stream characteristics, and (5) combining metrics into an index. Step 2 addressed the fact that some metrics (e.g., instream habitat structure and remoteness) use a scale of 0 to 20, other metrics use a percentage (e.g., percent embedded), and still others use a direct measure (e.g., riparian width in meters), by converting each metric to a common scale. Each metric was grouped into the following categories: structural, hydrological, vegetative, and visual appeal.

In step 3, reference and degraded sites were determined using the same criteria applied in developing the fish and benthic IBIs, minus the physical habitat criteria. In addition, the relationships of selected metrics, appropriate stream characteristics, and quantitative variables (e.g., discharge) to fish IBI scores or individual fish IBI metrics (e.g., species richness and abundance) were determined. Based on these results, criteria designating high and low biological integrity were added for determining reference and degraded sites.

After analyzing the discriminatory power of individual metrics and composite indices, the Coastal Plain PHI was defined as follows:

$$\text{PHI} = \frac{\text{INSTREAM HABITAT STRUCTURE} + \text{VELOCITY/DEPTH DIVERSITY} + \text{POOL QUALITY} - \text{EMBEDDEDNESS}/10 + \text{MAXIMUM DEPTH}/10 + \text{AESTHETIC QUALITY}/2}{6}$$

The non-Coastal Plain PHI was defined as follows:

$$\text{PHI} = \frac{\text{INSTREAM HABITAT STRUCTURE} + \text{VELOCITY/DEPTH DIVERSITY} + \text{RIFFLE QUALITY} - \text{EMBEDDEDNESS}/10 + 3 \text{ X (NUMBER OF ROOTWADS)} + \text{AESTHETIC QUALITY}/3}{6}$$

Four key physical habitat variables were common between both the Coastal Plain and the non-Coastal Plain: (1) instream habitat structure; (2) velocity/depth diversity; (3) embeddedness; and (4) aesthetic rating. Two additional variables were important in the Coastal Plain – pool/glide/eddy quality and maximum depth. Two other variables were important in the non-Coastal Plain – riffle/run quality and number of rootwads in a stream reach.

The index was then adjusted to a centile scale that rated each sample segment as follows:

- Scores of 72 to 100 are rated good
- Scores of 42 to 71.9 are rated fair
- Scores of 12 to 41.9 are rated poor
- Scores of 0 to 11.9 are rated very poor

7.3.2 Physical Habitat Index Results

Twenty percent of stream miles statewide had a PHI rating of good. The largest percentage of stream miles were in either fair (29%) or poor (29%) physical habitat condition (Figures 7-19 and 7-20). An estimated 22% of stream miles were in very poor condition.

PHI scores tended to increase with stream order. The statewide mean PHI score in first-order streams was 34, compared to a mean score of 57 in second-order and 67 in third-order streams. A far greater percentage of first-order stream miles were rated as very poor (29%) and poor (34%) than were second- or third-order counterparts. While the PHI rated 71% of second-order stream miles and 84% of third-order stream miles as good to fair, only 36% of first-order stream miles received that rating (Table 7-1). The lower ratings for first-order streams likely reflect the greater diversity of physical habitat available in larger streams. Many of the parameters in the PHI (e.g., instream habitat structure, velocity/depth diversity) tend to have higher scores in larger streams. The degree to which low scores are an artifact of stream size difference or, alternatively, indicate more degraded physical habitat in first-order streams, remains a question for further investigation. Because first-order streams make up the overwhelming majority of stream miles in Maryland, first-order stream results strongly influence the overall picture of stream conditions statewide and within basins.

The geographic distribution of PHI scores at sampled sites is shown on a statewide map (Figure 7-19). Sites with good PHI scores were found in all basins, although the greatest concentration was in the central Maryland Piedmont. Surprisingly, Western Maryland had a large concentration of sites rated poor or very poor by the PHI. This may reflect the prevalence of smaller streams in western Maryland, especially when compared to larger Piedmont streams found in the same PHI region (non-Coastal Plain).

Differences in PHI among basins (Figures 7-20 and 7-21, Table 7-1) were consistent with results for individual instream condition parameters (see section 7.2.4). The Elk basin, with 56% of stream miles in good condition, was a marked contrast to the Nanticoke/Wicomico, where 50% of stream miles were in very poor condition. No sites in the Elk or Choptank (1996 sampling) basins had PHI scores in the very poor range. The basins with the greatest percentage of stream miles in good to fair condition were the Elk (89%), Choptank (75% in 1996 sampling), Susquehanna (75%), Patapsco (71% in 1995 sampling), Bush (65%), and Gunpowder (64%). Each of these basins, except the Patapsco, had no poor or poor-to-marginal stream miles for at least one of the instream condition parameters evaluated in Section 7.2.4.

The basins with the greatest extent of poor and very poor physical habitat were the West Chesapeake (78%), Nanticoke/Wicomico (77%), Upper Potomac (73%), Youghiogheny (68% in both 1995 and 1997 sampling), Chester (68%), and North Branch Potomac (65%). In the West Chesapeake basin, individual instream condition parameters showed few miles with optimal habitat, especially for epifaunal substrate, velocity/depth diversity, pool/glide/eddy quality, and riffle/run quality. Other physical habitat parameters–bank stability, riparian buffer width, aesthetic quality, and remoteness–all had more than 25% of stream miles rated as optimal. This is one example of different individual parameters providing different assessments, indicating how different parameters factor into the overall PHI score. It should also be noted that the West Chesapeake streams sampled were generally smaller than average, whereas Elk streams (which tended to receive higher PHI scores) were larger than the statewide mean (see Section 7.2.6).

Mean PHI scores provide another basis of comparison among basins. The statewide mean PHI was 42. No basin had a mean PHI in the good range ($\geq$ 72). The highest mean PHI scores were reported in the Elk (71) and Choptank (65 in 1996 sampling). Other mean PHI estimates for basins fell between 26 and 55, corresponding with ratings of poor to fair.

7.4 ASSOCIATIONS BETWEEN PHYSICAL HABITAT DEGRADATION AND BIOLOGICAL CONDITION

The PHI scores were compared with fish IBI scores, benthic IBI scores, and the Hilsenhoff Biotic Index for each basin and statewide to identify whether an association exists between physical habitat quality and biotic integrity. For each statewide and basin comparison, regression analyses were used to compare the PHI and biological indicatorscores. PHI and IBI scores were also plotted against each other to investigate relationships between these indicators.

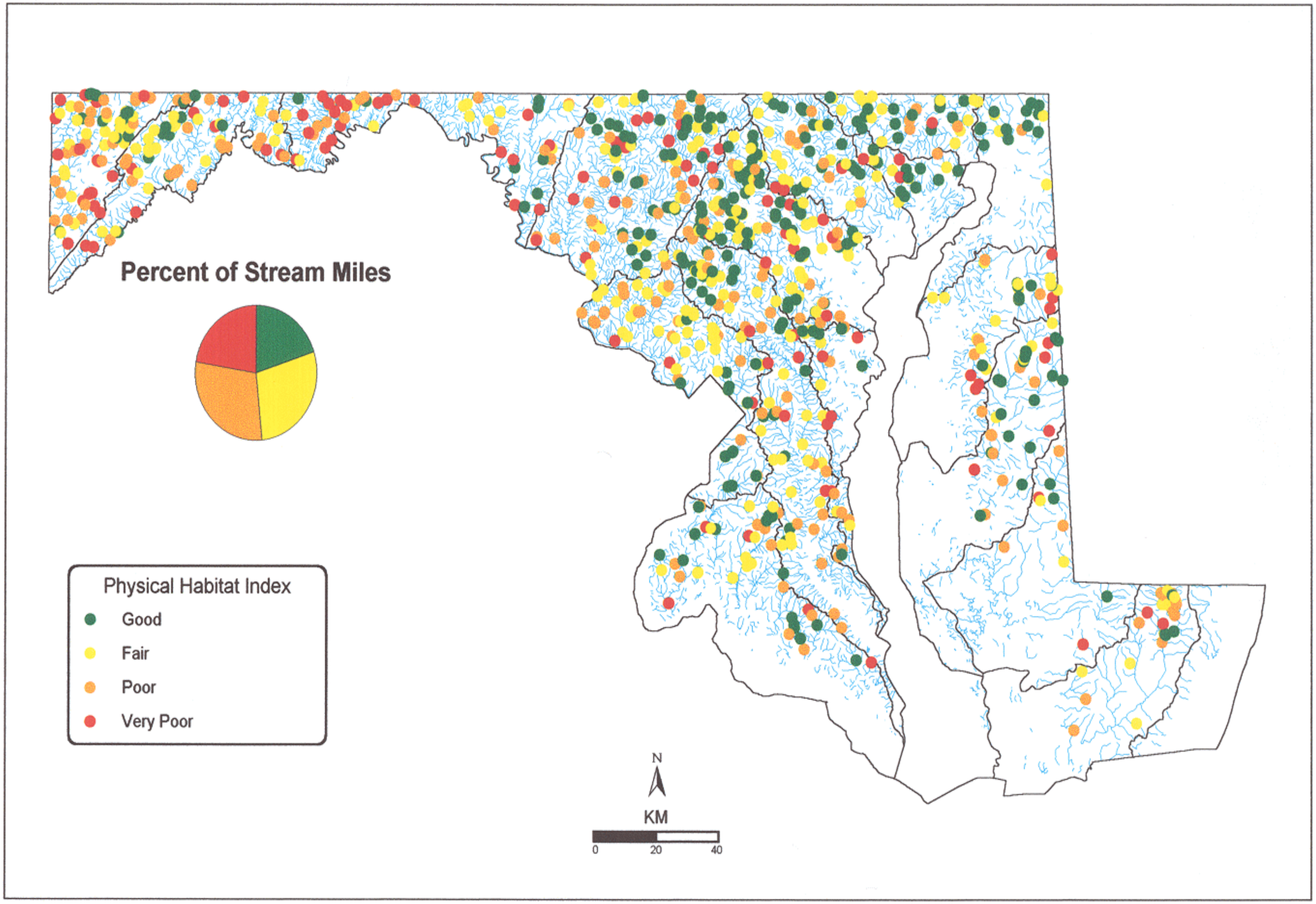

Figure 7-19. Geographic distribution of Physical Habitat Index (PHI) ratings for sites sampled in the 1995-1997 MBSS. Ratings are as follows: 72-100 good, 42-71.9 fair, 12 -41.9 poor, and 0-11.0 very poor.

Physical Habitat Index by Basin

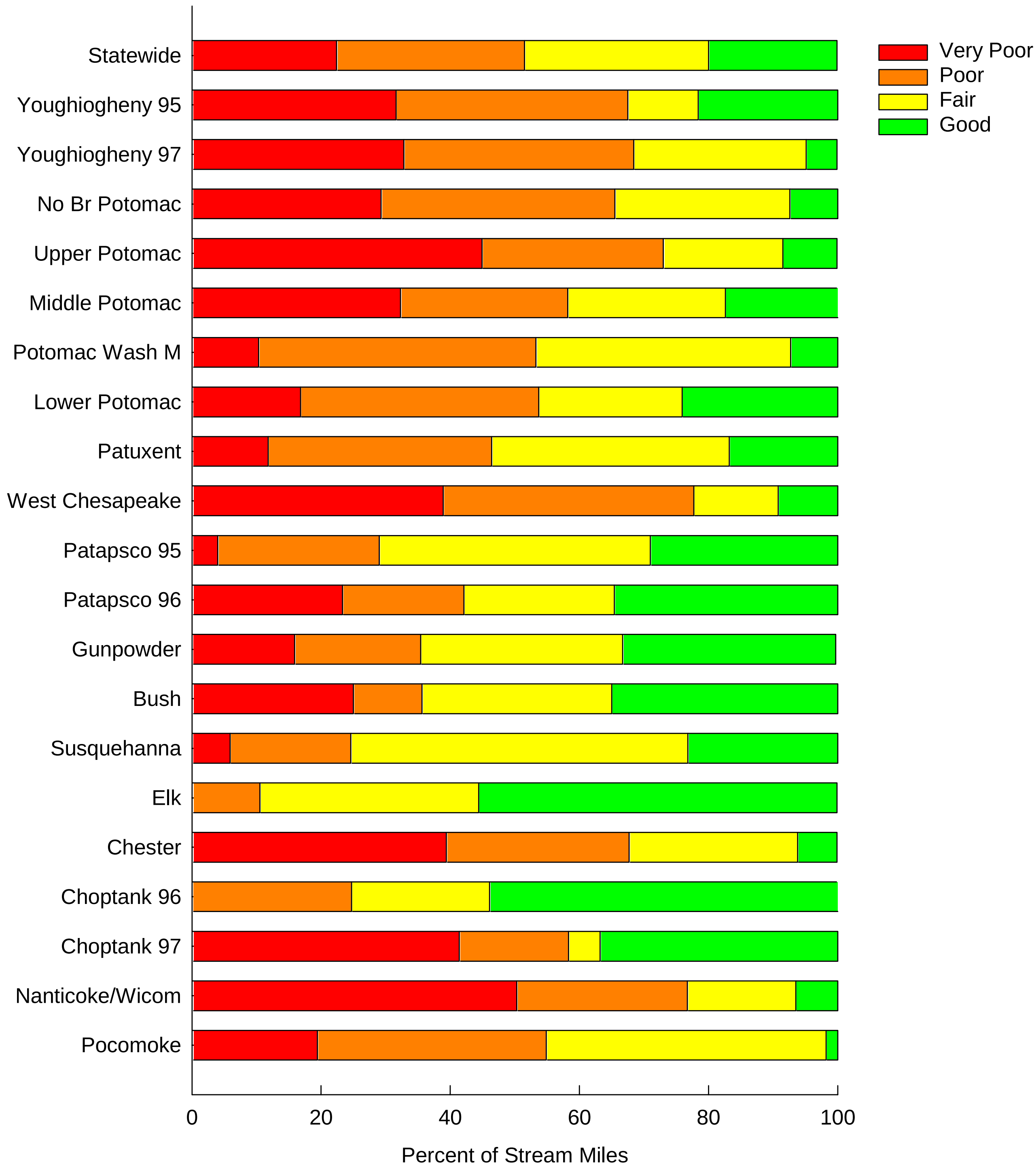

Figure 7-20. Physical Habitat Index (PHI) ratings for the basins sampled in the 1995-1997 MBSS, as the percentage of stream miles in each category. Ratings are as follows: 72-100 good, 42-71.9 fair, 12 -41.9 poor, and 0-11.0 very poor.

Table 7-1. Estimated percentage of stream miles in each PHI category for basins sampled in the 1995-1997 MBSS

	Good	**Std. Error**	**Fair**	**Std. Error**	**Poor**	**Std. Error**	**Very Poor**	**Std. Error**
Basin								
Youghiogheny 1995	21.6	9.1	10.9	6.8	35.9	11.6	31.6	11.5
Youghiogheny 1997	4.8	2.5	26.7	7.2	35.6	11.3	32.8	11.2
North Branch Potomac	7.4	2.7	27.1	6.8	36.2	9.3	29.3	9.2
Upper Potomac	8.4	2.4	18.5	6.1	28.1	7.7	44.9	8.8
Middle Potomac	17.5	2.6	24.4	5.4	25.9	6.0	32.3	6.8
Potomac Washington Metro	7.3	1.9	39.4	7.7	43.0	8.5	10.3	5.3
Lower Potomac	24.1	7.1	22.2	7.7	36.9	9.8	16.8	7.5
Patuxent	16.8	4.2	36.8	6.9	34.6	6.9	11.8	4.8
West Chesapeake	9.2	3.2	13.1	8.1	38.8	14.7	38.9	15.7
Patapsco 1995	29.0	6.6	42.0	8.7	25.0	7.8	4.0	3.4
Patapsco 1996	34.6	7.2	23.3	6.6	18.8	6.8	23.3	7.5
Gunpowder	33.2	8.5	31.3	8.5	19.5	7.7	15.9	7.4
Bush	35.0	12.4	29.4	14.8	10.6	10.6	25.0	14.6
Susquehanna	23.2	6.9	52.2	12.6	18.7	9.6	5.9	5.9
Elk	55.5	17.4	33.9	16.8	10.5	10.5	0.0	0.0
Chester	6.1	2.7	26.1	8.9	28.3	10.9	39.4	13.0
Choptank 1996	54.0	17.2	21.4	14.4	24.7	14.8	0.0	0.0
Choptank 1997	36.8	16.8	4.9	2.9	16.9	10.9	41.4	18.2
Nanticoke/Wicomico	6.5	2.9	16.8	11.5	26.4	13.8	50.3	17.7
Pocomoke	1.8	0.9	43.3	17.3	35.5	15.7	19.4	13.2
Stream Order								
1	10.9	4.8	25.8	9.4	34.2	5.3	29.1	9.8
2	36.0	8.1	35.0	6.5	19.6	5.8	9.4	5.9
3	50.0	12.7	34.2	14.6	13.1	9.7	2.7	4.0
Statewide	19.9	3.8	28.5	7.4	29.1	3.5	22.4	7.6

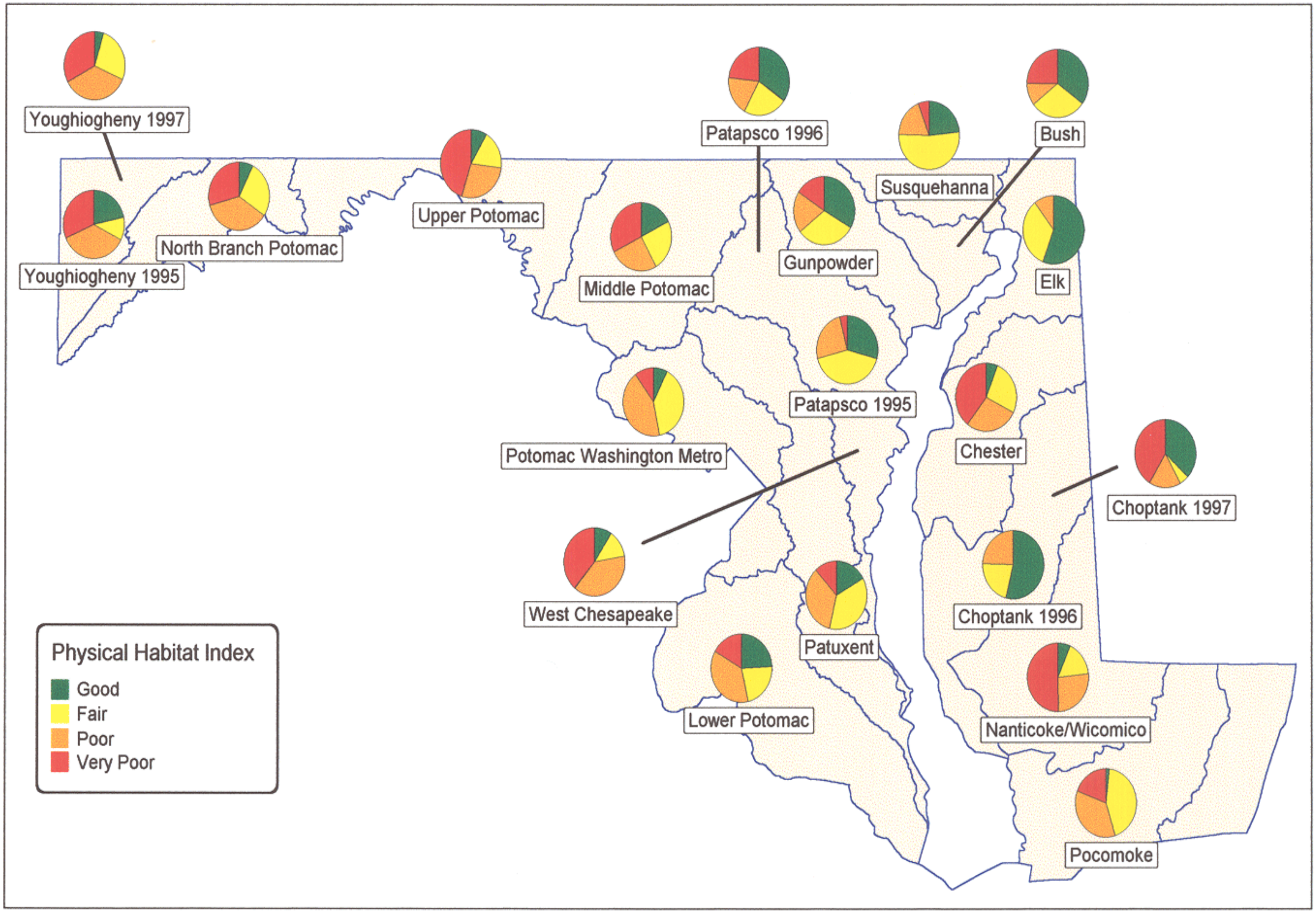

Figure 7-21. Distribution of Physical Habitat Index (PHI) ratings for the basins sampled in the 1995-1997 MBSS as the percentage of stream miles in each category. Ratings are as follows: 72-100 good, 42-71.9 fair, 12 -41.9 poor, and 0-11.0 very poor.

A significant positive relationship was found between the PHI and the fish IBI for all basins (Table 7-2, Figure 7-22). The strength of the relationship varied, but was found to be significant for all basins (linear regression, $p<0.02$), with between 12 and 58% of the variability in the data explained by the relationship between PHI and fish IBI. Statewide, the relationship was significant ($p<0.001$, $r^2=0.28$). The basins with the strongest relationships were the Bush, Nanticoke/Wicomico, Lower Potomac, and Middle Potomac.

There was a significant positive relationship between the PHI and benthic IBI both statewide and in seven individual basins (Table 7-2, Figure 7-23). Statewide, the relationship was significant ($p<0.01$) and 19% of the variability in the data was explained by the relationship between the PHI and benthic IBI. The individual basins for which a significant relationship ($p<0.05$) was found were the Middle Potomac, Lower Potomac, Patuxent, West Chesapeake, Chester, Choptank, and Nanticoke/Wicomico (r^2 values ranging from 0.05 to 0.42).

No significant relationship was found between the PHI and Hilsenhoff Biotic Index when all sites sampled statewide were pooled (Table 7-2). A significant negative correlation was found in three of the basins, the Patuxent, Chester, and Choptank. This overall lack of correlation with the PHI confirms that the Hilsenhoff Biotic Index is most appropriate for assessing organic enrichment in other water chemistry conditions rather than differences in physical habitat conditions.

Although a biotic integrity index has not yet been developed for amphibians and reptiles, presence/absence data on these groups was compared with physical habitat conditions as assessed by the PHI. The number of amphibian and reptile species per site increased with PHI scores. Numbers of both aquatic and terrestrial species increased slightly in areas with good physical habitat, compared to areas of less favorable physical habitat (Figure 7-24). However, these increases were within the range of error for these estimates. Given their affinity for particular habitat features, certain species (e.g., streamside salamanders), may prove to be better indicators of physical habitat quality.

7.5 RELATIONSHIPS BETWEEN INDIVIDUAL PHYSICAL HABITAT FACTORS AND BIOTA

In addition to the associations with the PHI, numerous relationships between biota and individual physical habitat parameters were explored using 1995-1997 MBSS data. Selected examples are presented below.

Given the relationship between fish IBI and PHI scores, further analyses were conducted to determine which individual physical habitat parameters had the strongest associations with the fish IBI. Individual parameters were compared with the fish IBI in box-and-whisker and scatter plots of statewide data. Most of the individual parameters in the PHI showed a relationship with fish IBI scores. For example, fish IBI scores increased with instream habitat structure (Figure 7-25), aesthetic quality (Figure 7-26), and maximum depth (Figure 7-27). Instream habitat structure is a direct assessment of instream conditions important to fish. In contrast, aesthetic quality provides a general rating of the degree of human impact at a site.

Similar plots were constructed to compare individual habitat parameters with benthic IBI scores. Some relationships between habitat and benthic IBI were evident. For example, the benthic IBI increased with riffle quality (Figure 7-28) and aesthetic quality (Figure 7-29). Maximum depth and the abundance of woody debris did not show associations with the benthic IBI. Embeddedness, a factor that would be expected to directly affect benthic habitat, exhibited a great deal of variability with benthic IBI scores. In several basins (Middle Potomac, Potomac Washington Metro, Lower Potomac, Patuxent, Patapsco, and Gunpowder), benthic IBI scores decreased with increased embeddedness, consistent with declines that would occur where sedimentation has degraded stream bottom habitat. In a few basins (Pocomoke, Nanticoke/Wicomico, and West Chesapeake), there was no apparent relationship between IBI scores and embeddedness. High embeddedness scores were common in these basins and appeared to represent natural conditions in silt-bottom streams. This condition would not necessarily be detrimental to benthic species adapted to Coastal Plain streams.

Fish and benthic IBI scores were also compared with a number of physical habitat parameters not included in the overall PHI. As expected, both indices increased slightly with riparian buffer width (Figure 7-30). Benthic IBI scores increased with epifaunal substrate score (Figure 7-31), suggesting this parameter is useful for assessing benthic habitat quality. Both the fish and benthic IBIs decreased with low channel alteration scores, a significant finding given the widespread evidence of channel alteration in Maryland streams.

The presence of riparian buffer vegetation is important to amphibian and reptile species as well. The number of amphibian and reptile species per site increased with riparian buffer width, a pattern followed by both aquatic and terrestrial species (Figure 7-32). Terrestrial amphibian and reptile species were slightly more numerous at forested

Table 7-2. Regression relationships between the Physical Habitat Index and other biological indicators, 1995-1997 MBSS. Only those basins where the relationship was significant are shown.

Basin	p value	r^2
PHI and Fish IBI		
Statewide	0.0001	0.28
Youghiogheny	0.0001	0.20
North Branch Potomac	0.0001	0.37
Upper Potomac	0.0018	0.18
Middle Potomac	0.0001	0.43
Potomac Washington Metro	0.001	0.17
Lower Potomac	0.0001	0.43
Patuxent	0.0004	0.17
West Chesapeake	0.0039	0.32
Patapsco	0.0001	0.13
Gunpowder	0.0033	0.23
Bush	0.0004	0.58
Susquehanna	0.0021	0.28
Elk	0.0093	0.37
Chester	0.004	0.32
Choptank	0.0144	0.17
Nanticoke/Wicomico	0.0023	0.50
Pocomoke	0.007	0.29
PHI and Benthic IBI		
Statewide	0.0002	0.02
Middle Potomac	0.0236	0.05
Lower Potomac	0.0001	0.30
Patuxent	0.0009	0.13
West Chesapeake	0.0012	0.30
Chester	0.0001	0.42
Choptank	0.0089	0.18
Nanticoke/Wicomico	0.0165	0.33
PHI and Hilsenhoff Biotic Index		
Patuxent	0.0005	0.16
Chester	0.0009	0.31
Choptank	0.0445	0.11

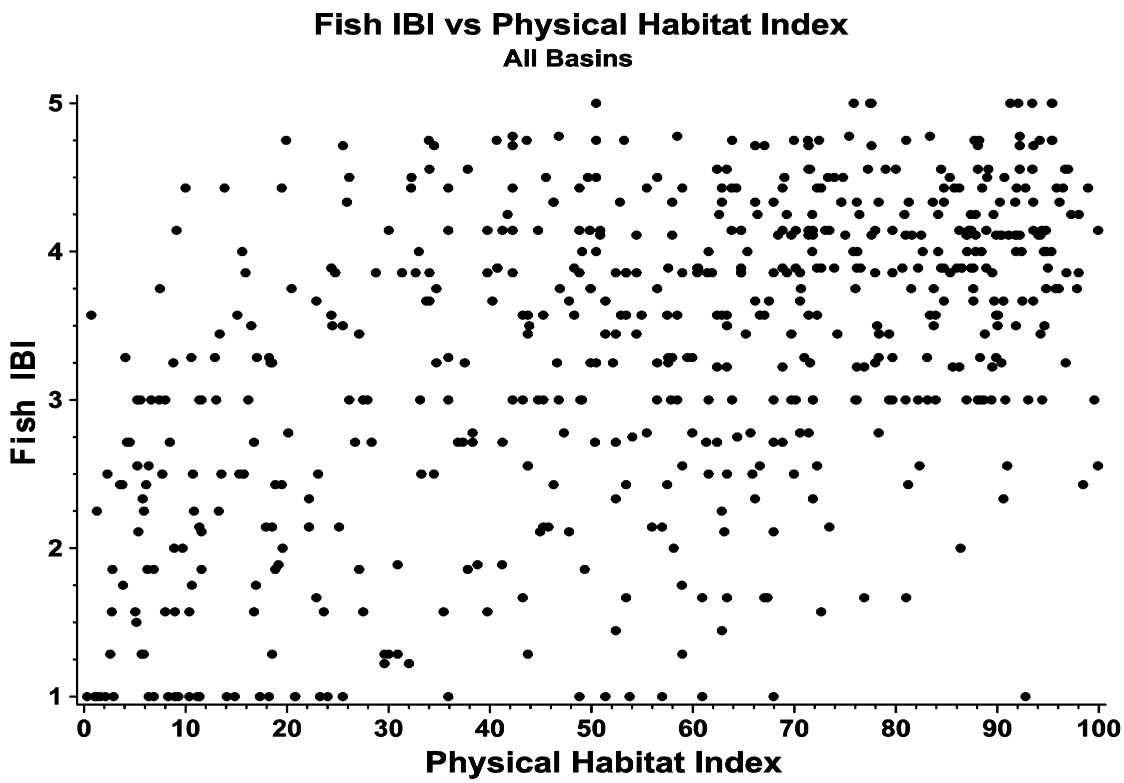

Figure 7-22. Relationship between the fish IBI and the Physical Habitat Index (PHI), statewide for the 1995-1997 MBSS

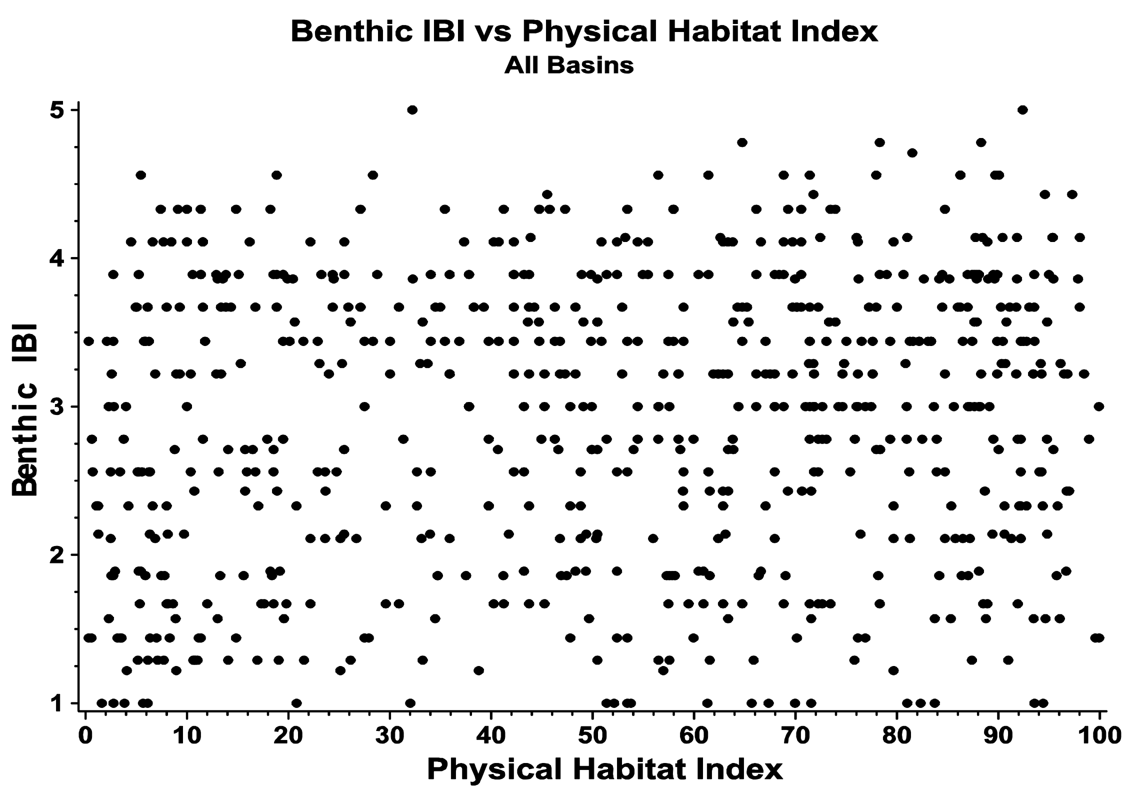

Figure 7-23. Relationship between the benthic IBI and the Physical Habitat Index (PHI), statewide for the 1995-1997 MBSS

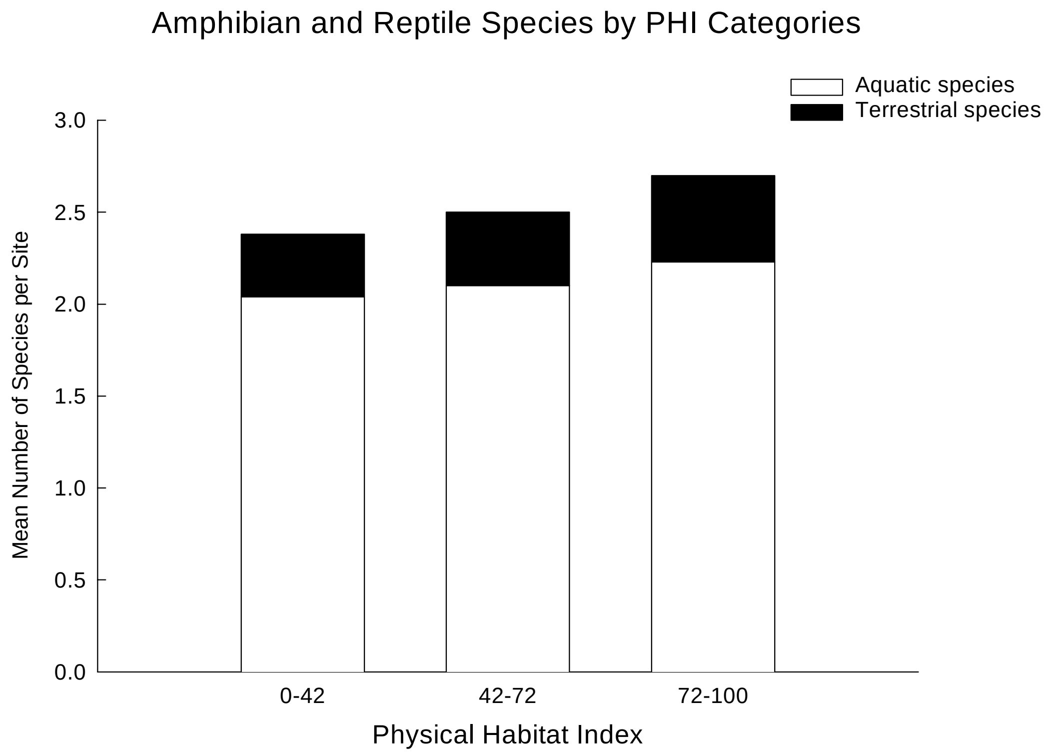

Figure 7-24. Mean number of amphibian and reptile species in three categories of the Physical Habitat Index (PHI) for the 1995-1997 MBSS

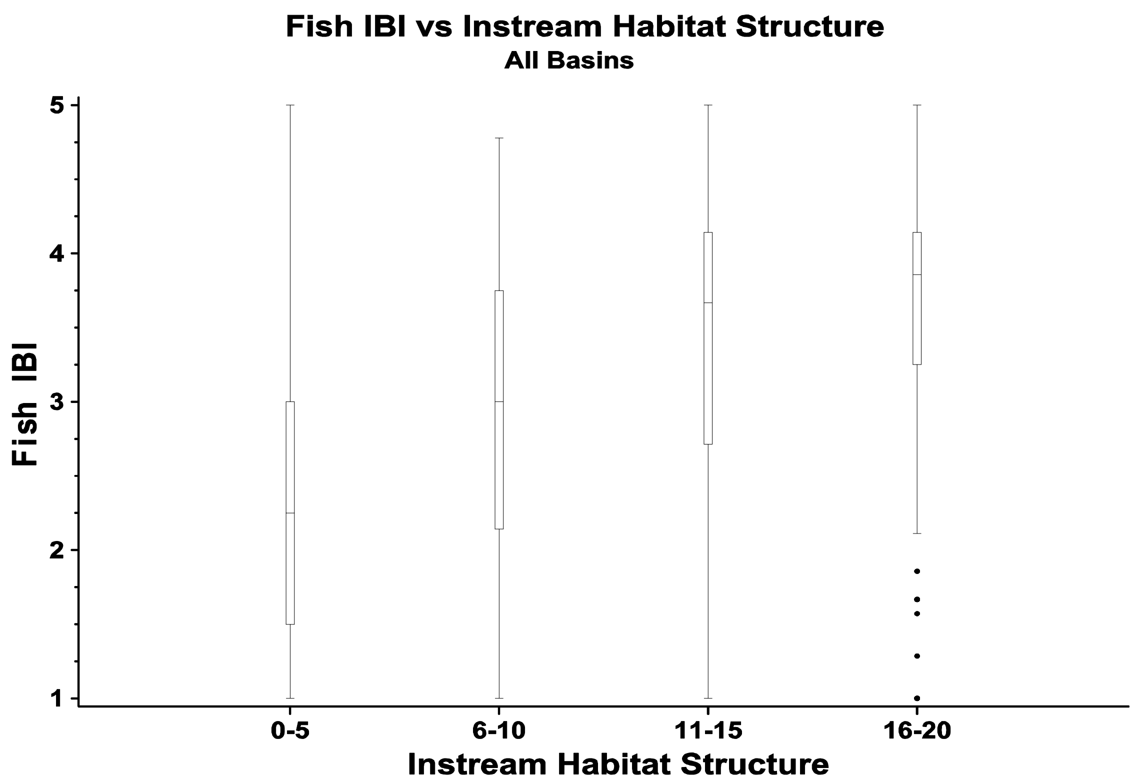

Figure 7-25. Relationship between the fish IBI and instream habitat structure, statewide for the 1995-1997 MBSS. In box-and-whisker plots, the box indicates the 25th percentile, median, and 75th percentile of values. Vertical lines designate the range of values; dots indicate outliers (values beyond 1.5 times the interquartile range).

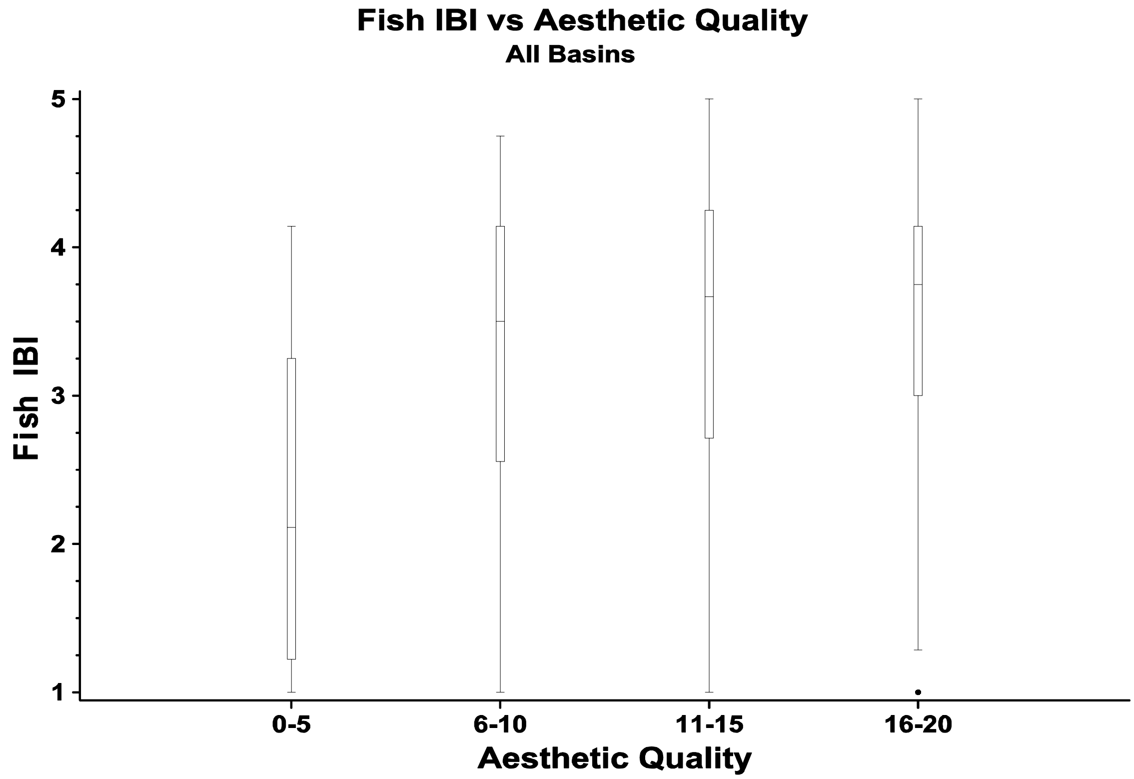

Figure 7-26. Relationship between the fish IBI and aesthetic quality, statewide for the 1995-1997 MBSS

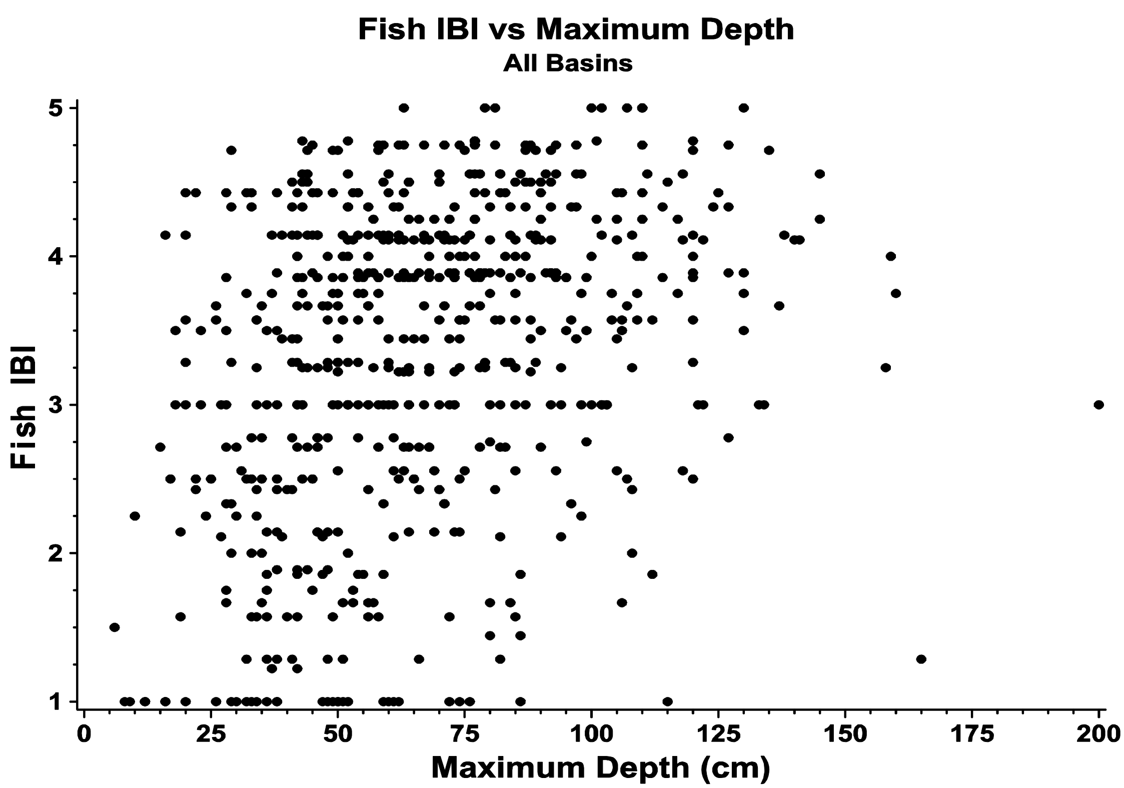

Figure 7-27. Relationship between the fish IBI and maximum depth, statewide for the 1995-1997 MBSS

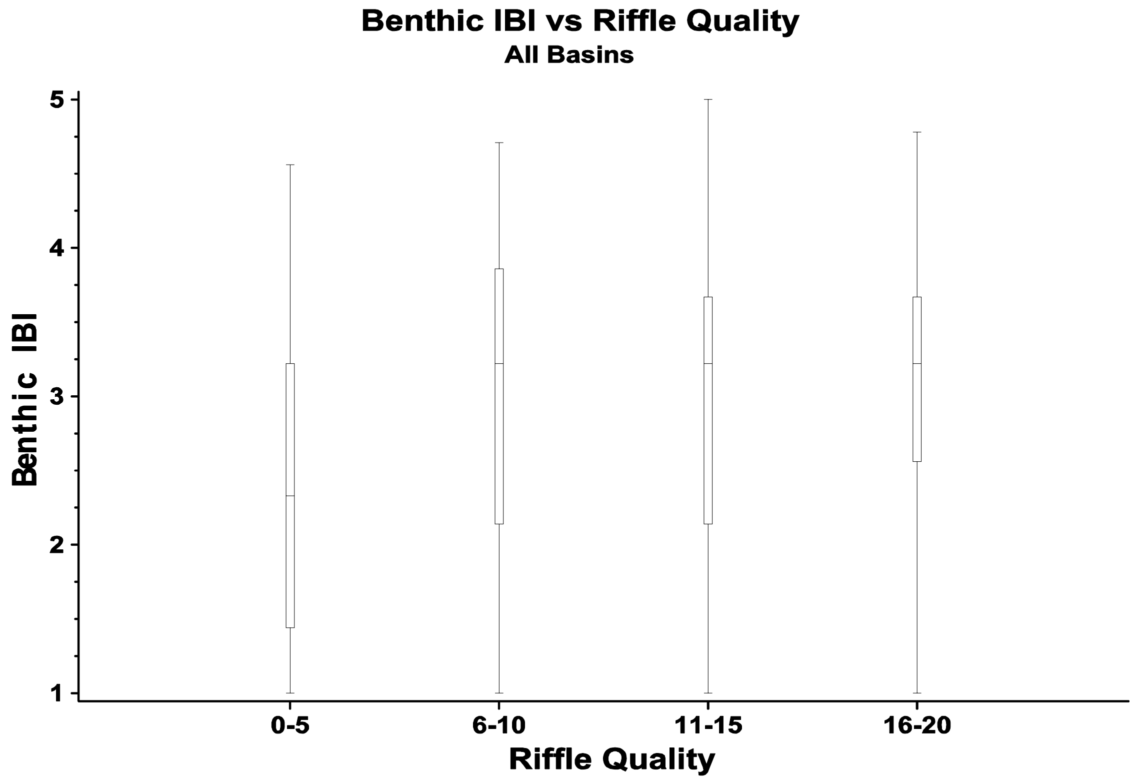

Figure 7-28. Relationship between the benthic IBI and riffle/run quality, statewide for the 1995-1997 MBSS

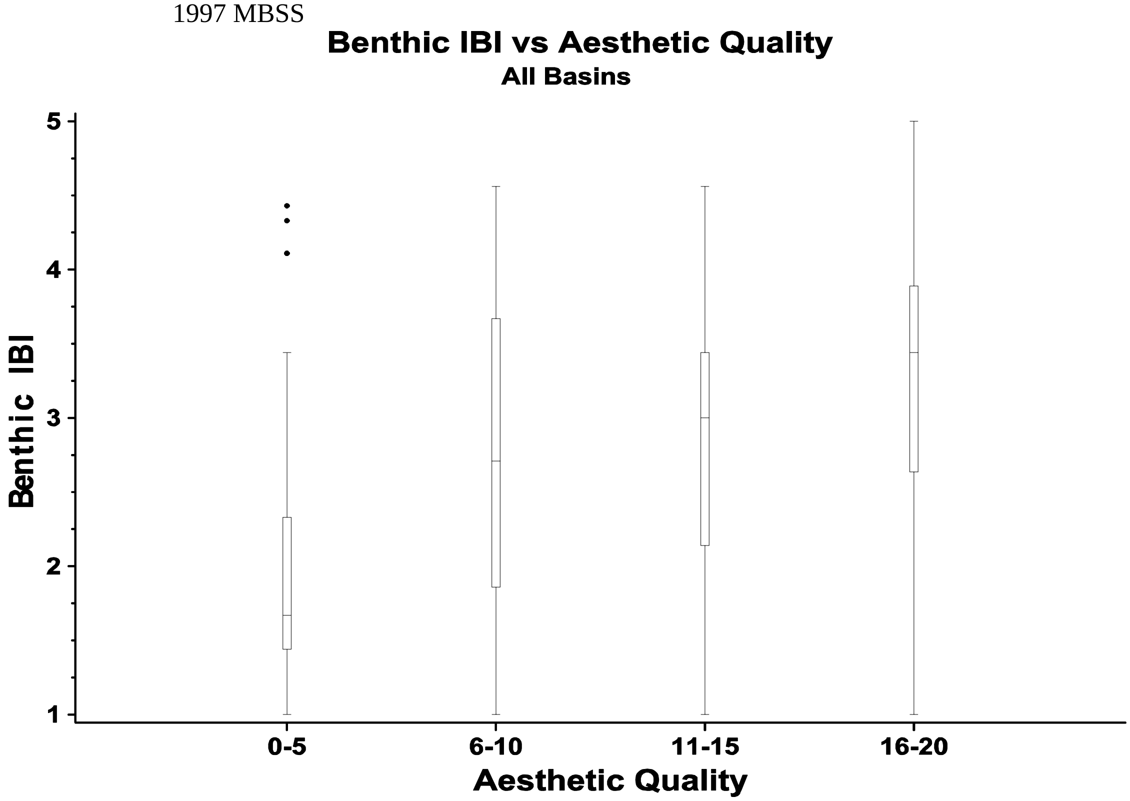

Figure 7-29. Relationship between the benthic IBI and aesthetic quality, statewide for the 1995-1997 MBSS

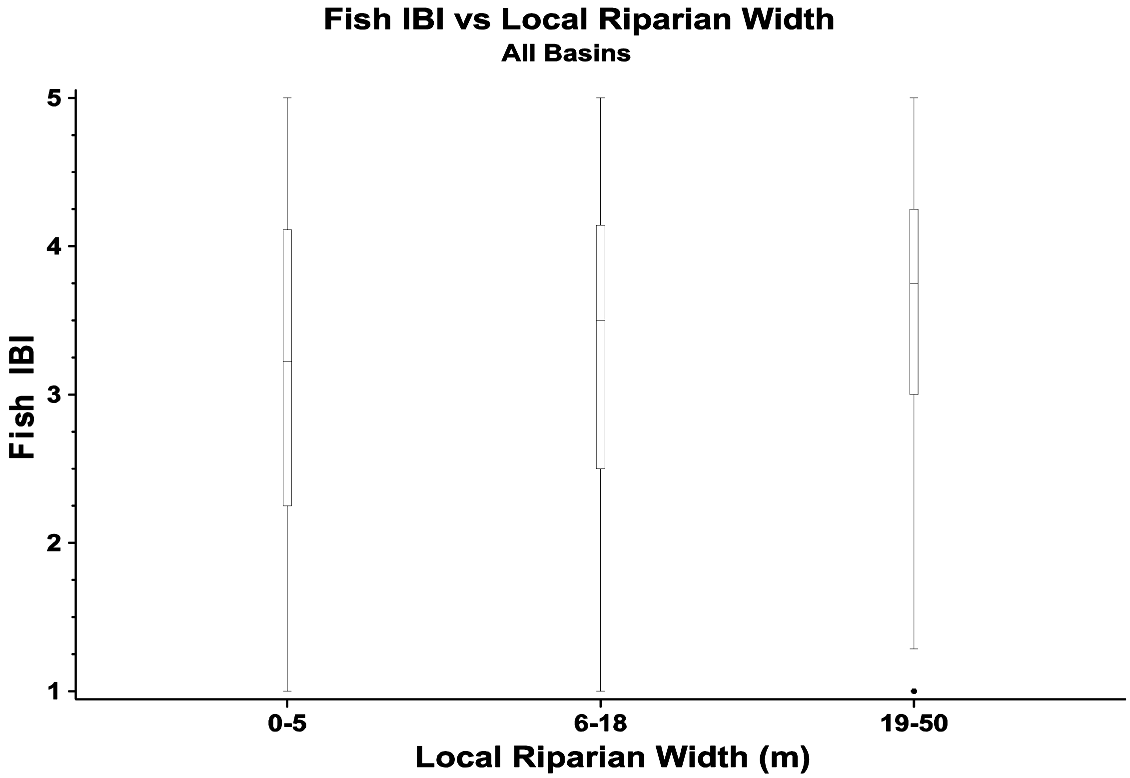

Figure 7-30. Relationship between the fish IBI and local riparian buffer width, statewide for the 1995-1997 MBSS

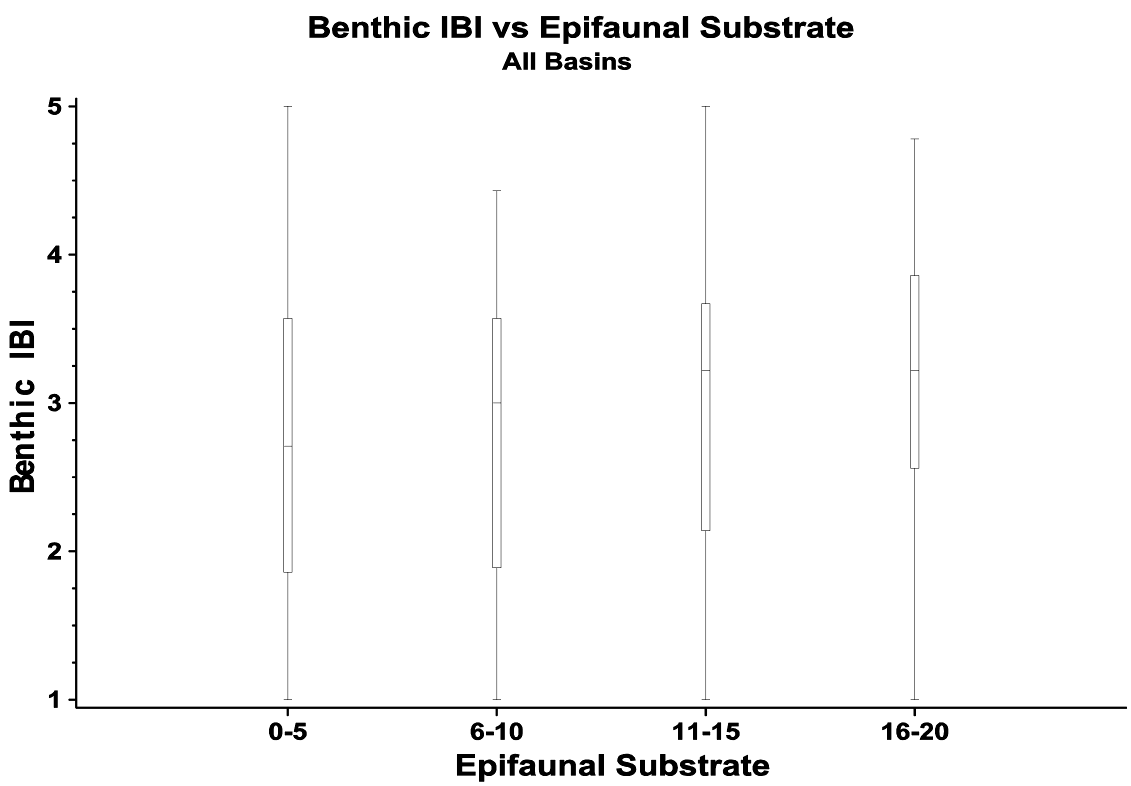

Figure 7-31. Relationship between the benthic IBI and epifaunal substrate, statewide for the 1995-1997 MBSS

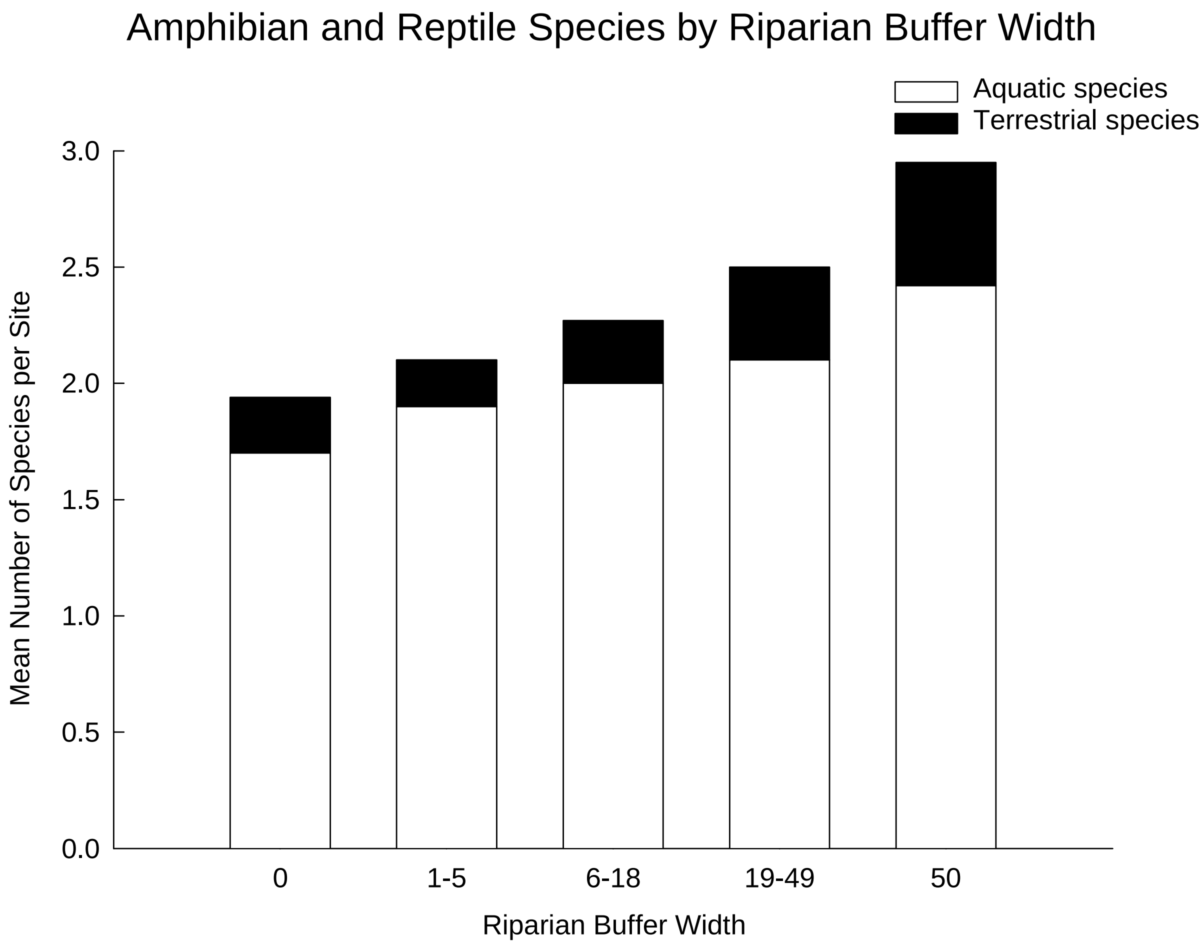

Figure 7-32. Mean number of amphibian and reptile species per site for each category of riparian buffer width, statewide, for the 1995-1997 MBSS

sites, while aquatic species were more common at grassy or wetland sites, although these differences were within the range of error of these estimates.

A stream's remoteness may influence species with particular ecological requirements or a need for undisturbed habitat. Also, remote sites are less accessible to anglers, which could affect gamefish populations. To test the influence of remoteness, brook trout densities were compared between remote and non-remote sites. Remote sites were defined as sites receiving an optimal remoteness score (at least 16 points out of 20). Statewide, brook trout density was estimated at 54 individuals per stream mile. Among remote sites, density was 138 brook trout per stream mile, compared with 36 individuals per stream mile at non-remote

sites. In particular, brook trout density was higher at remote sites in the Gunpowder and Youghiogheny (1995 sampling), but not in other basins. The percentage of harvestable-sized brook trout (>6 inches total length) did not increase with remoteness, but the density of harvestable-sized brook trout did increase. Statewide, 17% of brook trout were of harvestable size. An estimated 15% of brook trout in remote streams were of harvestable size, compared with 19% at non-remote sites. A notable exception was in the North Branch Potomac, the basin with the greatest overall percentage of harvestable-sized brook trout (35%). Within this basin, the percentage of harvestable brook trout was an impressive 66% at remote sites, compared with 26% in non-remote streams.